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DIVISION OF SUNDSTRAND CORPORATION  
ROCKFORD, ILLINOIS

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June 1971

AN EXPERIMENTAL STUDY OF  
NOZZLES AND SPECIFIC HEAT RATIO  
EFFECTS ON OFF-DESIGN PERFORMANCE  
OF PARTIAL ADMISSION TURBINES

PREPARED BY

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FOR THE  
OFFICE OF NAVAL RESEARCH  
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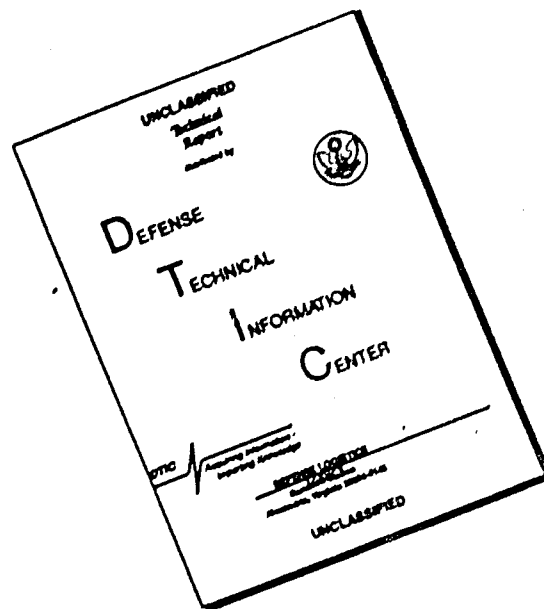
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this document may be better  
studied on microfiche

FOR THE  
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WASHINGTON, D.C.

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SUMMARY

In attaining optimum turbine performance, the nozzle is the single most influential component. Small, high specific energy turbines, generally operating at high pressure ratios, require supersonic converging-diverging nozzles for high efficiency. Such nozzles, however, yield poor performance at off-design pressure ratios. The object of this study was to obtain design information to improve performance.

A comprehensive experimental program was undertaken to optimize nozzle divergence and evaluate plug nozzles and the off-design effects of specific heat ratio. No real analysis work was to be performed under this contract with discussion and presentation sufficient only to serve as a guide to use of the report.

Nozzle performance was evaluated from test measurements of a complete turbine-nozzle system. All nozzles were tested on nitrogen and in Phase III, the nozzle which had shown the best performance on nitrogen was tested with Argon ( $\gamma = 1.40$ ) and Freon 13 ( $\gamma = 1.18$ ) to evaluate the effects of specific heat ratio. All testing was done with the same rotor. A total of eleven different nozzles were tested; 5 straight conical designs with the same design Mach Number (2.5) and area ratio, but different divergence angles downstream of the throat ( $7^\circ$  to  $15^\circ$  half angle), a similar program with nozzles of design mach no. = 4, two annular throat plug nozzles and a 2 dimensional "half plug" design.

Results show that an optimum nozzle divergence exists but not for all conditions. The  $11^\circ$  and  $13^\circ$  half angle nozzles maintain a consistent advantage in peak efficiency and range capability (minimum variation in efficiency during off-design pressure ratio operation), but only with the lower design pressure ratio nozzles tested ( $M_D = 2.5$ ). No such clear advantage appeared in the results of the  $M_D = 4.0$  nozzles tested; the performance of all divergence angles seemed to merge into one band of width on the same order as the scatter although the narrow ( $7^\circ$ ) nozzle displayed a small advantage in peak efficiency.

Plug nozzles exhibited no significant performance advantage over straight conical designs - their range (efficiency variation) appears marginally better in a few cases but the peak efficiency is consistently lower than the poorest conical design tested in the mach 2.5 series, and this more than makes up for it.



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The effect of specific heat ratio seems to be a small reduction of peak efficiency and improved range (less efficiency variation over a range of pressure ratios).

Off-design speed effects as revealed by the shape of the  $u/C_0 - \eta_T$  curve (pointed vs wide) appeared small throughout the study.

**INTRODUCTION**

Many military turbine applications require operation over a wide range of pressure ratios. Such applications would include any underwater device operating at varying depth and aero-space vehicles such as missiles aircraft and space vehicles that operate from sea level to outer space. This off-design regime often accounts for a significant portion of the mission profile.

Nozzle and rotor performance has a large effect on the ultimate obtainable turbine efficiency with the nozzle being much the more important, hence under a previous contract (N00014-66-C-0204) Sundstrand conducted a turbine off-design performance study, reported on in Reference 1; Sundstrand AER 486, dated April 1967, "Effect of Nozzle Geometry on Off-Design Performance of Partial Admission Impulse Turbines".

The present study extends the work done under the previous contract although primarily an experimental program whereas the previous one was principally analytical in nature.

The objectives of this study were to (I) experimentally optimize the divergence angle of straight conical supersonic turbine nozzles, (II) determine what, if any, off-design advantage can be gained with plug nozzles, (III) determine the effect of specific heat ratio on off-design performance.

## 1.0 EXPERIMENTAL APPARATUS, TEST TECHNIQUES AND DATA REDUCTION

This study was made using a test dynamometer designed and built by Sundstrand. The test apparatus and techniques were developed over a number of years while performing various turbine research and development studies.

### 1.1 TURBINE TEST DYNAMOMETER

The turbine test facility is illustrated in Figure 1 and is specifically designed to evaluate the effects of turbine geometry on performance. Rapid changes in rotors, nozzles, and rotor tip and side clearances are easily made. Shaft power is determined by a torque arm force measurement, the load being applied by an electrical homopolar dynamometer. Turbine bearing losses are included in the torque arm measurement since the entire rotating group is supported by special low friction ball bearings. The dynamometer is shown in Figures 2, 3 and 4. Typical test hardware is shown in Figure 5.

The facility is capable of testing turbines at pressure ratios up to 2500. The entire test unit is located in a vacuum chamber during tests such that exhaust pressures as low as 0.25 psia are possible. The maximum test turbine speed is 40,000 rpm. Turbine diameters up to approximately 7 inches can be accommodated. Output shaft power levels of up to 20 hp can be absorbed by the electrical load bank.

Tests to obtain turbine efficiency as a function of turbine geometry, pressure ratio, speed, and Reynolds number can be conducted.

Testing shows an average scatter of 5% in the turbine efficiency data (about 3 points). This scatter appears to be random, yielding an accurate and reliable mean when curve fitting techniques are used with large quantities of data, as in this present study. The nozzle flow rate is measured by an orifice plate flowmeter showing scatter in the flow data of .75%. Instrumentation to obtain complete pressure and temperature data throughout the turbine can be employed.

All tests were made with the shrouded turbine wheel and turbine exhaust housing shown in Figure 5. During all tests the radial tip clearance was .050 inch; the axial clearance between the nozzle and the wheel was .035 inch. Table III presents geometric parameters that were common during all tests and Table IV summarizes test conditions.

## 1.2 TURBINE NOZZLE TEST CONFIGURATIONS

Three types of nozzles were studied; straight conical, axi symmetric plug nozzles (two styles), and a 2-dimensional or "half plug" design.

### 1.2.1 Conical Nozzles

All conical nozzles are in the same nozzle plate and were tested individually with the remainder plugged. The plate includes two sets of five nozzles of different design conditions ( $M_D = 2.5$ ,  $A/A^* = 2.63$ , and  $M_D = 4.0$ ,  $A/A^* = 10.72$ ) with divergence half angles  $\alpha_c$  from  $7^\circ$  to  $15^\circ$  in each set. The exit diameter of all conical nozzles is .282 inch. The relationship between nozzle exit and blades is shown in Figure 8. The conical nozzles are quite simple in design and are sketched with dimensions tabulated in Figure 6.

The conical nozzles were selected as the basis of comparison in this study since they are the most common type used in partial admission turbines.

### 1.2.2 Plug Nozzles

The plug nozzles are illustrated in Figure 7. The annular throat nozzles ("A" and "B") were designed per the procedure of Rao (Reference 2) and both have an exit diameter of .280. The 2-dimensional half plug (c) was also designed per his procedure, with an exit height of .280 and a throat height of .162. The design mach number of all plug nozzles was 2.5, for easy comparison with the  $M_D = 2.5$  conicals.

All plug nozzles were machined in the same plate with their centerlines tangent to a common pitch diameter of 5.96 inch as were the conicals.

### 1.3 TEST TECHNIQUES

A test run was made by pressurizing the turbine inlet to a prescribed value (not greater than 240 psia) and adjusting the turbine back pressure to the prescribed level to obtain the desired pressure ratio. Data was then taken at 6 or 7 turbine speeds from 7000 to 35000 rpm. The speed was controlled by adjustment of the homopolar alternator load resistance (coarse adjustment) and the field voltage (fine adjustment). After the speed range was covered by increasing speed, the points were retaken as it was decreased back to the starting speed in order to minimize effects of mechanical hysteresis, resulting in 11 to 14 points per test run. Next the back pressure was adjusted to the next prescribed pressure ratio and the speed points repeated. At 5 pressure ratios per nozzle this resulted in approximately 55 to 65 data points per nozzle test and a program total of over 700.

The turbine pressure ratio was evaluated by measuring the pressure in the turbine nozzle plenum chamber, which the nozzle plate seats against, and pressure in the exhaust duct just downstream of the turbine. The turbine flow rate was measured by an orifice meter in the inlet line leading to the turbine plenum. At each data point conditions were allowed to stabilize before recording the data and then proceeding to the next point. Approximately three minutes of run time were required at each data point. With one exception, all pressures (and torque, which was reflected as a differential pressure) were detected with pressure transducers and recorded automatically on a strip chart. The orifice plate pressure was read on a Bourdon pressure gage and written manually on the chart and orifice plate  $\Delta P$  was detected with a Bailey pressure transmitter and recorded on the strip chart. All temperatures were measured with copper constantan thermocouples and recorded on the trace. Speed was measured with a magnetic pickup and recorded manually from an electronic counter.

The torque readout device was calibrated before and after each run by the application of dead weight to the torque arm. If significant variations in the pre- and post-calibration points occurred, the data was discarded and a rerun made.

The data were recorded and later reduced by a computer program to obtain the desired performance parameters. The flow rate was determined from the orifice measurements as well as the perfect gas choked flow equation. In this manner the flow discharge coefficient was obtained; if an unexplainable variation in this coefficient was found the data was discarded as unreliable and the test was rerun.

#### 1.4 DATA REDUCTION PROCEDURES

The data was reduced utilizing an IBM 1130 computer. The data reduction program (Sundstrand E2) includes curve fits of compressibility factor and ratio of specific heats for nitrogen, obtained from Reference 4. These properties are calculated as functions of local static temperature and pressure, and can be input when a gas other than nitrogen is used as the test fluid.

This program calculates the turbine gas flow from both the orifice measurements and from the perfect gas relationship for choked nozzles. Comparison of these two values yields the nozzle discharge coefficient. The turbine efficiency is then calculated based upon (1) the measured torque, speed, and orifice flow rate values and (2) the measured temperature difference. The second calculation is for a comparison only, since no attempt to obtain an adiabatic process was made. Other parameters such as the specific speed, specific diameter, torque coefficient, shaft horsepower, adiabatic head, velocity ratio, and wheel tip speed are also calculated.

The reduced turbine efficiency data is estimated to have an accuracy of 5%. This is considered acceptable in light of the fact it appears random with no systematic errors, strongly suggesting that the mean value is a valid representation of the true efficiency with the large quantities of data available.

To reduce the effect of irregular or scattered data points a least squares curve fit program was written and the data processed and cross plotted. An indication of the validity of this procedure is that the resulting computer plots agree in almost all predominant trends and values with some 25 manual summary plots made while data was being collected, and where the two disagree the computer plots appear the more reasonable.

## LEAST SQUARES DATA SMOOTHING PROGRAM

The output of program E-2 was used in the least squares program to arrive at a smoothed data representation. To further reduce the effect of scatter, sets of data points were grouped together.

The general equation of the surface took the form:

$$\begin{aligned} \eta_T = & A_1 + A_2 \left( \frac{u}{C_0} \right) + A_3 \left( \frac{u}{C_0} \right)^2 + A_4 \left( \frac{u}{C_0} \right)^3 \\ & + A_5 X + A_6 X^2 + A_7 X^3 + A_8 \left( \frac{u}{C_0} \right) X \\ & + A_9 \left( \frac{u}{C_0} \right)^2 X + A_{10} \left( \frac{u}{C_0} \right) X^2 \end{aligned}$$

For most groups of data (Groups I-V, and IX-XIII) the variable X represented nozzle half angle. For all other groups the variable X represented pressure ratio. Data groups XV-XVIII included only the first four terms of the general equation, and since only (3) mach 4.0 nozzles were tested the seventh term was omitted for all mach 4.0 data groups.

A listing of all data groups is shown on Table I.

These least square equations were used to form the smooth curves appearing on all computer made plots in this report. The plots were made on a "CAL COMP" plotter controlled by a subroutine called GRAF on Sundstrand's IBM 1130.

Empirical data points were omitted from the summary plots to illustrate trends more clearly. Instead, for reference they are shown on plots in Appendix A and listed in Appendix B.

It should be remembered when studying any one data set and curve, that the shape and position of the curve has been influenced by other data in that group not shown on the plot.

**DATA LISTING**

Appendix B contains a listing of all data points, a comparison of the empirical and smoothed data, and a rough measure of scatter for each point.

**Scatter Percent Eff.**

$$= (\text{Empirical Data Point} - \text{Smoothed Data Point}) \times 100.$$

**Scatter Percent Val.**

$$= (\text{Scatter Percent Eff.}) / (\text{Empirical Data Point})$$

Table II explains the exact interpretation of the titles appearing under the heading nozzle designation.



TABLE I  
LIST OF DATA GROUPS

GROUP	NOZZLE DESIGNATIONS	APPROXIMATE PRESSURE RATIO	TEST GAS
I	Mach 2.5, 15° Half Angle	25:1	Nitrogen
	Mach 2.5, 13° Half Angle	25:1	Nitrogen
	Mach 2.5, 11° Half Angle	25:1	Nitrogen
	Mach 2.5, 9° Half Angle	25:1	Nitrogen
	Mach 2.5, 7° Half Angle	25:1	Nitrogen
II	Mach 2.5, 15° Half Angle	20:1	Nitrogen
	Mach 2.5, 13° Half Angle	20:1	Nitrogen
	Mach 2.5, 11° Half Angle	20:1	Nitrogen
	Mach 2.5, 9° Half Angle	20:1	Nitrogen
	Mach 2.5, 7° Half Angle	20:1	Nitrogen
III	Mach 2.5, 15° Half Angle	17:1	Nitrogen
	Mach 2.5, 13° Half Angle	17:1	Nitrogen
	Mach 2.5, 11° Half Angle	17:1 Design	Nitrogen
	Mach 2.5, 9° Half Angle	17:1	Nitrogen
	Mach 2.5, 7° Half Angle	17:1	Nitrogen
IV	Mach 2.5, 15° Half Angle	15:1	Nitrogen
	Mach 2.5, 13° Half Angle	15:1	Nitrogen
	Mach 2.5, 11° Half Angle	15:1	Nitrogen
	Mach 2.5, 9° Half Angle	15:1	Nitrogen
	Mach 2.5, 7° Half Angle	15:1	Nitrogen
V	Mach 2.5, 15° Half Angle	12:1	Nitrogen
	Mach 2.5, 13° Half Angle	12:1	Nitrogen
	Mach 2.5, 11° Half Angle	12:1	Nitrogen
	Mach 2.5, 9° Half Angle	12:1	Nitrogen
	Mach 2.5, 7° Half Angle	12:1	Nitrogen
VI	Plug Nozzle 'A'	25:1	Nitrogen
	Plug Nozzle 'A'	20:1	Nitrogen
	Plug Nozzle 'A'	17:1 Design	Nitrogen
	Plug Nozzle 'A'	15:1	Nitrogen
	Plug Nozzle 'A'	12:1	Nitrogen
VII	Plug Nozzle 'B'	25:1	Nitrogen
	Plug Nozzle 'B'	20:1	Nitrogen
	Plug Nozzle 'B'	17:1 Design	Nitrogen
	Plug Nozzle 'B'	15:1	Nitrogen
	Plug Nozzle 'B'	12:1	Nitrogen

TABLE I (CONTINUED)

GROUP	NOZZLE DESIGNATIONS	APPROXIMATE PRESSURE RATIO	TEST GAS
VIII	Plug Nozzle 'C'	25:1	Nitrogen
	Plug Nozzle 'C'	20:1	Nitrogen
	Plug Nozzle 'C'	17:1	Nitrogen
	Plug Nozzle 'C'	15:1	Nitrogen
	Plug Nozzle 'C'	12:1	Nitrogen
IX	Mach 4.0, 15° Half Angle	200:1	Nitrogen
	Mach 4.0, 11° Half Angle	200:1	Nitrogen
	Mach 4.0, 7° Half Angle	200:1	Nitrogen
X	Mach 4.0, 15° Half Angle	150:1	Nitrogen
	Mach 4.0, 11° Half Angle	150:1 Design	Nitrogen
	Mach 4.0, 7° Half Angle	150:1	Nitrogen
XI	Mach 4.0, 15° Half Angle	100:1	Nitrogen
	Mach 4.0, 11° Half Angle	100:1	Nitrogen
	Mach 4.0, 7° Half Angle	100:1	Nitrogen
XII	Mach 4.0, 15° Half Angle	50:1	Nitrogen
	Mach 4.0, 11° Half Angle	50:1	Nitrogen
	Mach 4.0, 7° Half Angle	50:1	Nitrogen
XIII	Mach 4.0, 15° Half Angle	25:1	Nitrogen
	Mach 4.0, 11° Half Angle	25:1	Nitrogen
	Mach 4.0, 7° Half Angle	25:1	Nitrogen
XIV	Mach 2.5, 11° Half Angle	35:1	Argon
	Mach 2.5, 11° Half Angle	28:1	Argon
	Mach 2.5, 11° Half Angle	25:1 Design	Argon
	Mach 2.5, 11° Half Angle	21:1	Argon
	Mach 2.5, 11° Half Angle	17:1	Argon
XV	Mach 4.0, 11° Half Angle	80:1	Nitrogen
XVI	Mach 4.0, 11° Half Angle	60:1	Nitrogen
XVII	Mach 4.0, 11° Half Angle	40:1	Nitrogen
XVIII	Mach 2.5, 11° Half Angle	13:1 Design	Freon 13

TABLE II  
LIST OF NOZZLE DESIGNATIONS

NOZZLE DESIGNATION	INTERPRETATION
2.57	Mach 2.5 Nozzle, 7° Half Angle Nitrogen Test
2.59	Mach 2.5 Nozzle, 9° Half Angle Nitrogen Test
2.511	Mach 2.5 Nozzle, 11° Half Angle Nitrogen Test
2.513	Mach 2.5 Nozzle, 13° Half Angle Nitrogen Test
2.515	Mach 2.5 Nozzle, 15° Half Angle Nitrogen Test
4.7	Mach 4.0 Nozzle, 7° Half Angle Nitrogen Test
4.11	Mach 4.0 Nozzle, 11° Half Angle Nitrogen Test
4.15	Mach 4.0 Nozzle, 15° Half Angle Nitrogen Test
Plug 'A'	Plug Nozzle 'A', Nitrogen Test (See Figure 7)
Plug 'B'	Plug Nozzle 'B', Nitrogen Test (See Figure 7)
Plug 'C'	Plug Nozzle 'C', Nitrogen Test (See Figure 7)
Argon 2.511	Mach 2.5 Nozzle, 11° Half Angle Argon Test
Freon 2.511	Mach 2.5 Nozzle, 11° Half Angle Freon Test

TABLE III  
TURBINE AND NOZZLE DATA  
COMMON TO ALL TEST CONFIGURATIONS\*

Nozzle:

Nozzle Angle.....	16°
Exit Diameter.....	.28 inch
Pitch Diameter.....	5.96 inches
Number of Nozzles.....	1.0

Rotor:

Pitch Diameter.....	5.78 inches
Blade Angles (inlet and exit).....	25°
Blade Height.....	0.42 inch
Blade Chord.....	0.3 inch
Number of Blades.....	115

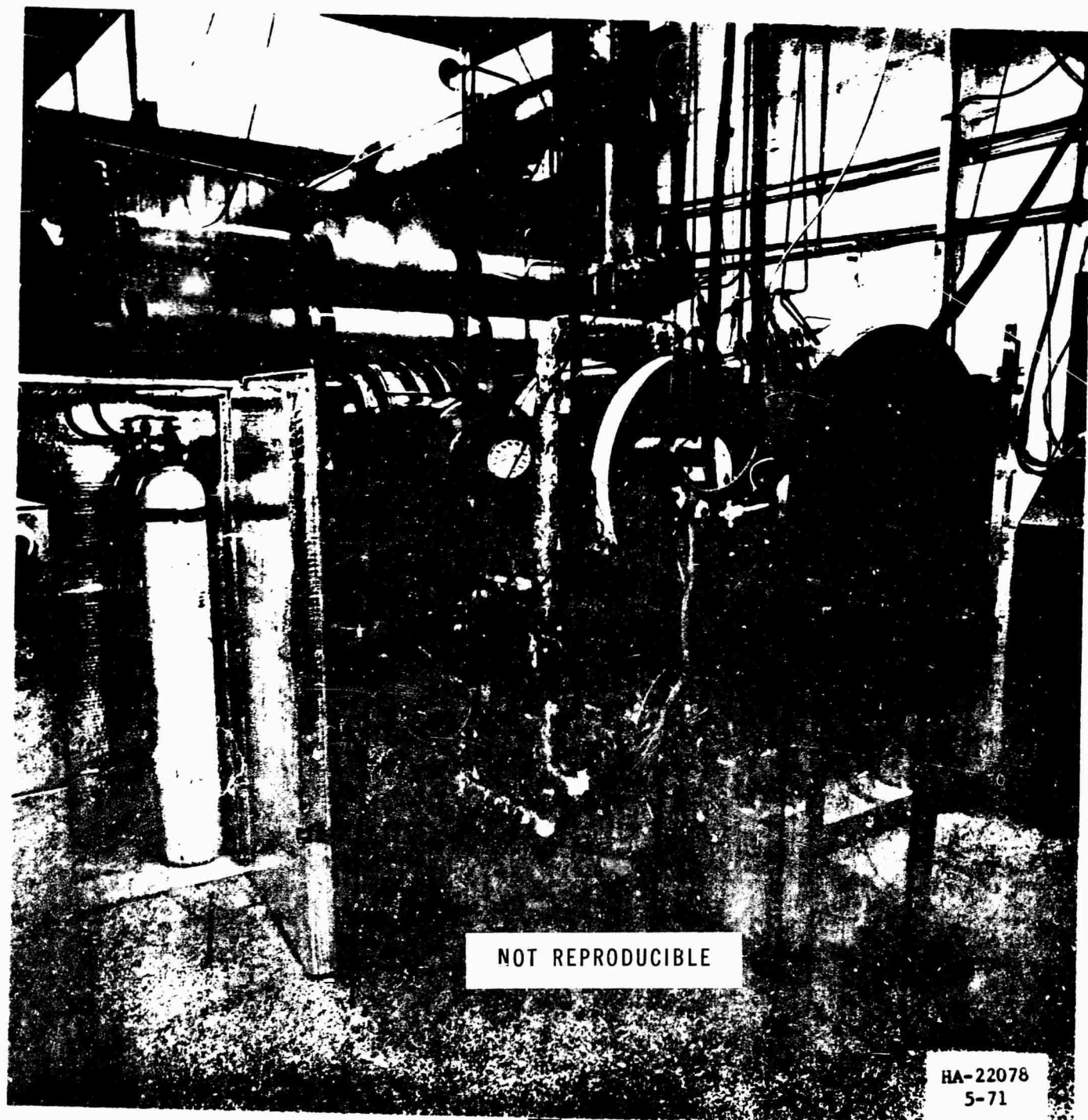
Clearances:

Rotor Tip Radial.....	.050 inch
Nozzle To Rotor.....	0.035 inch
Rotor To Exhaust Housing.....	.060 inch

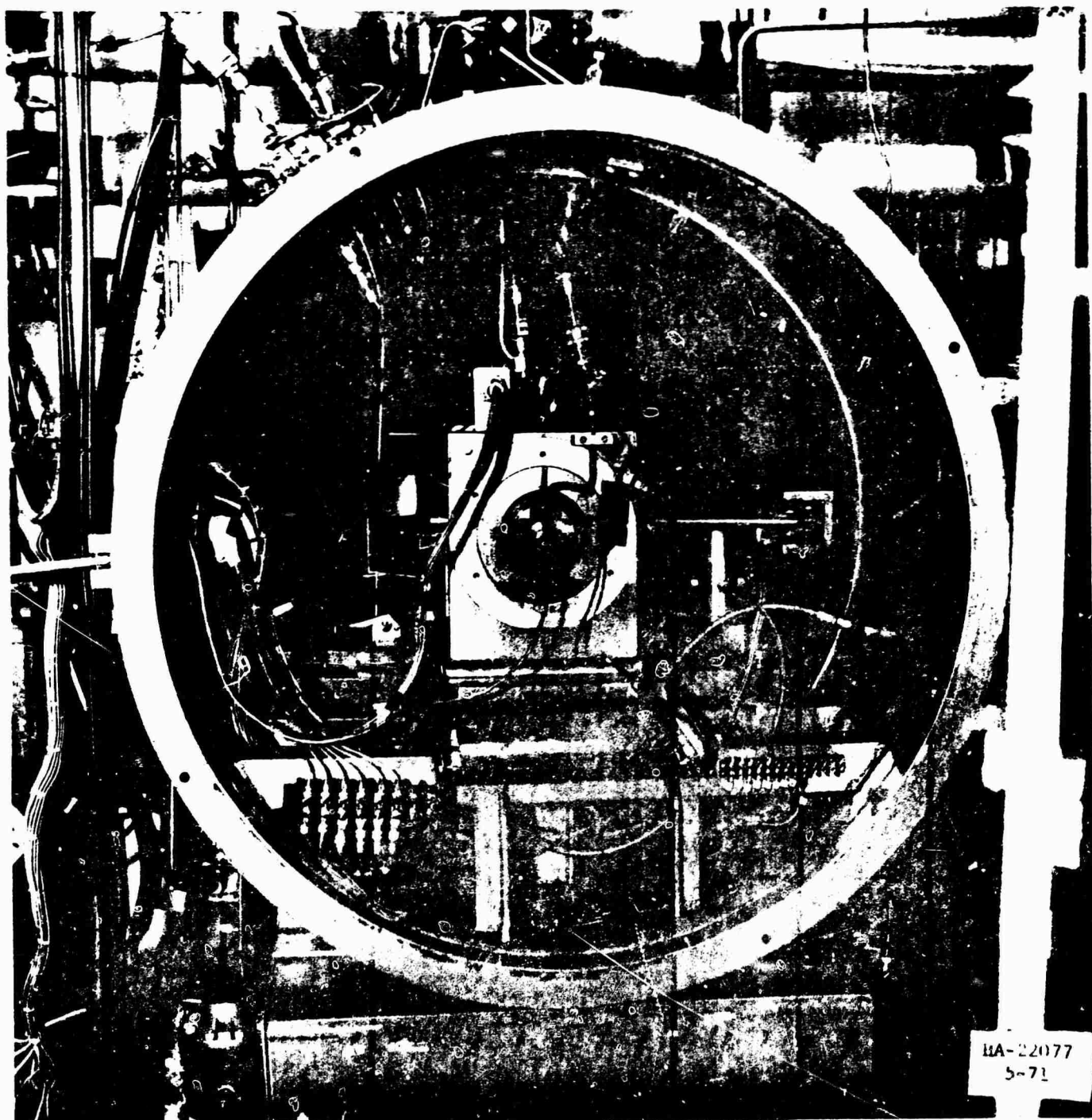
Gas Conditions

Inlet Temperature.....	Approx. 20-60°F
Inlet Pressure.....	Up To 240 psia

\*Unless exception noted



— FIGURE 1 TURBINE TEST  
CHAMBER AND APPARATUS. —



— FIGURE 2 INSIDE OF TEST  
CHAMBER WITH RIG INSTALLED —

HA-22124  
6-71

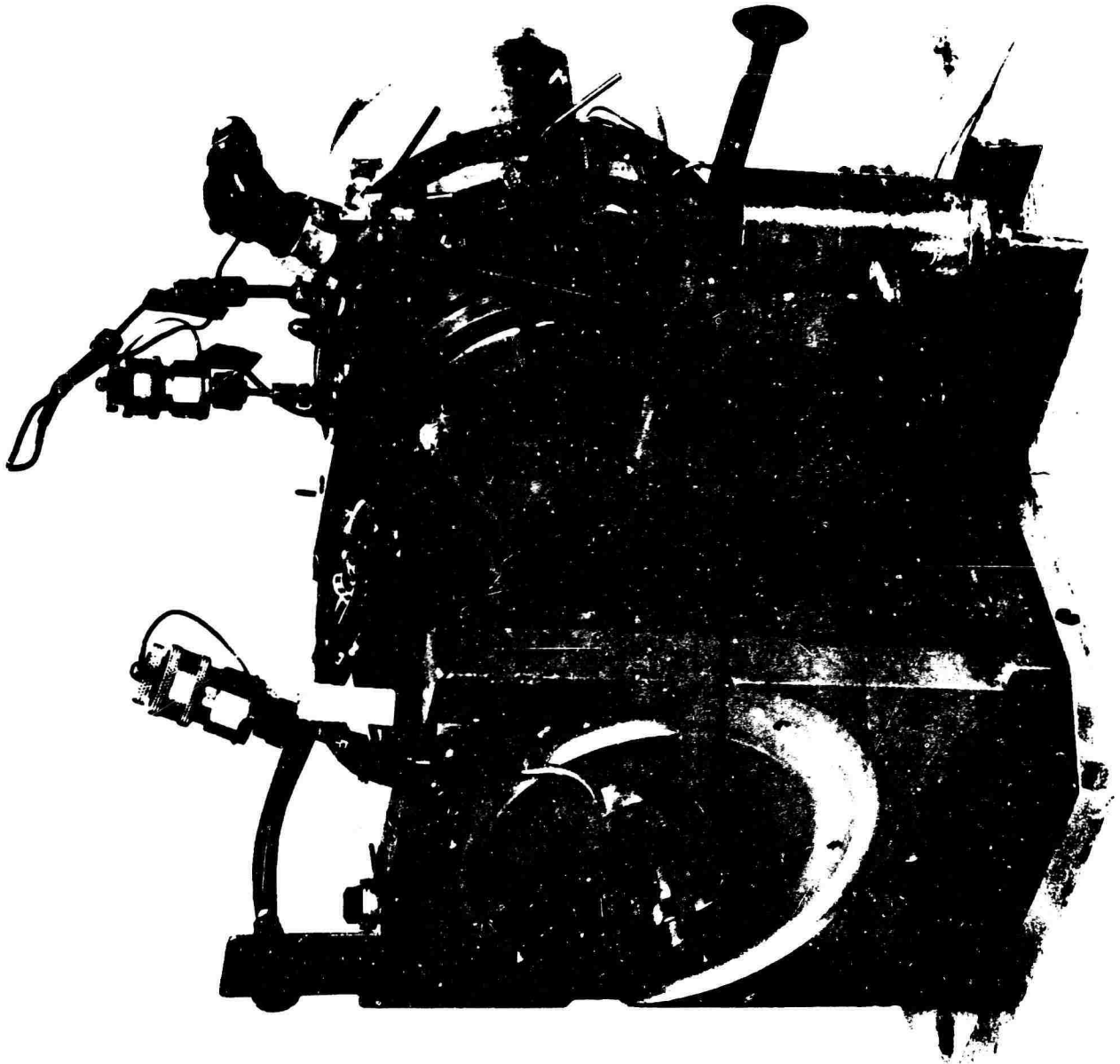
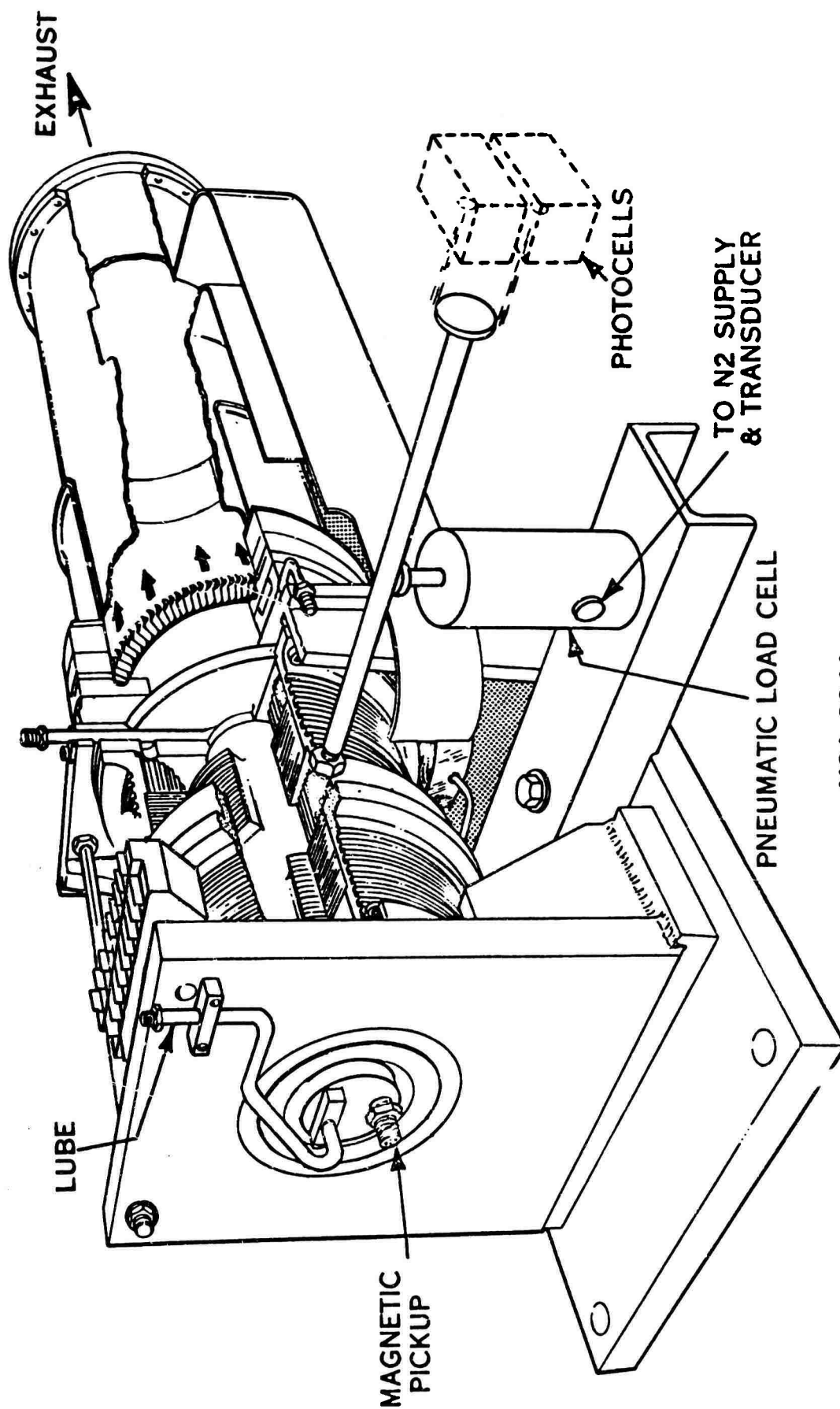


FIGURE 3 TURBINE TEST RIG



MSA 394A

— FIGURE 4 TURBINE TEST RIG —  
DIAGRAM



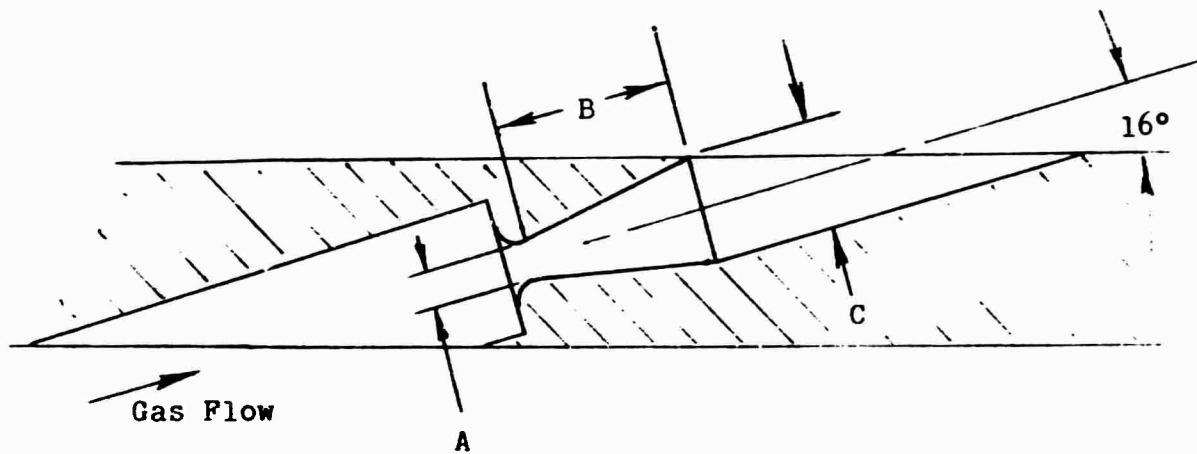
HA-22125  
6-71



FIGURE 5 TEST RIG AND  
COMPONENTS

# TYPICAL NOZZLE CROSS SECTION

ATR 2001  
PAGE 17



$\gamma = 1.4$				
Design Mach No.	Divergence Angle	Dim. A	Dim. E	Dim. C
2.5	14°	.173	.4439	.282
2.5	18°	.173	.3441	.282
2.5	22°	.173	.2804	.282
2.5	26°	.173	.2361	.282
2.5	30°	.173	.2034	.282
4.0	14°	.086	.7982	.282
4.0	18°	.086	.6188	.282
4.0	22°	.086	.5042	.282
4.0	26°	.086	.4245	.282
4.0	30°	.086	.3657	.282

Dim C = Constant permits identical nozzle height/blade height ratio for both expansion ratios.

Figure 6 Conical Nozzles Tested

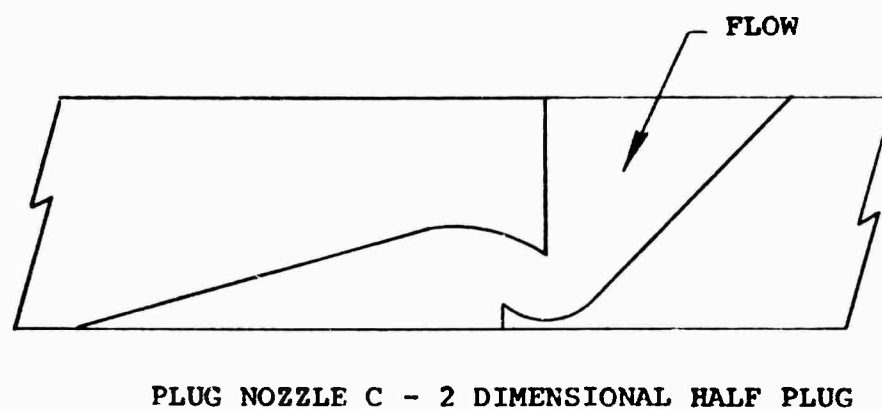
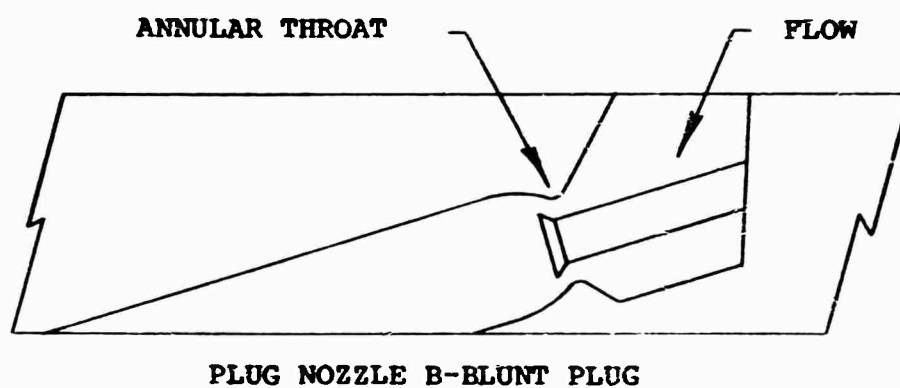
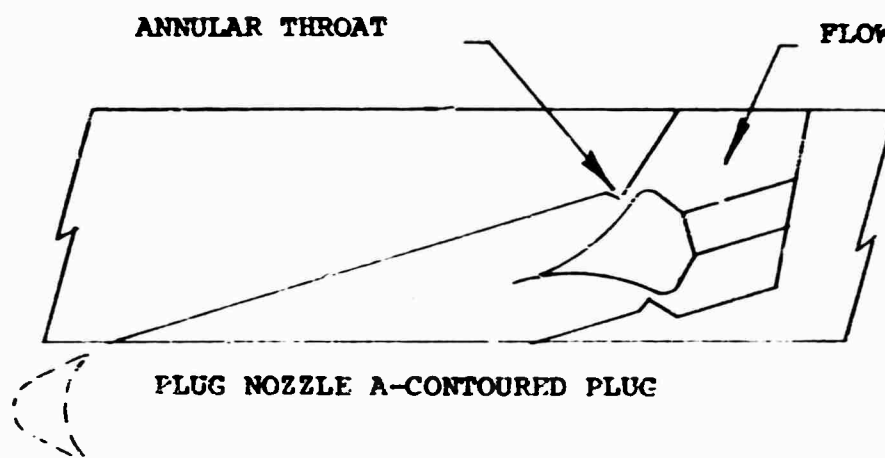


FIGURE 7 - PLUG NOZZLES TESTED



CONICAL NOZZLE EXIT AND ROTOR OUT LINE -  
LOOKING THROUGH ROTOR BLADES

2.0

EXPERIMENTAL RESULTS AND DISCUSSION

The work of this program can be divided into three phases or subprograms:

- Phase I      Nozzle divergence angle evaluations -  
                    7° to 15° half angle. (Figure 6). Five nozzles  
                    of design mach no = 2.0 and three of  $M_D = 4.0$   
                    were tested.
- Phase II      Evaluation of performance of three styles of plug  
                    nozzles (Figure 7):  
                    Plug Nozzle "A" - Pointed Plug  
                    Plug Nozzle "B" - Blunt Plug  
                    Plug Nozzle "C" - 2-dimensional Half Plug
- Phase III      Tests to determine the effect of specific heat  
                    ratio on performance. Tests were made at  
                     $\gamma = 1.18, 1.40, 1.68$ .

Nominal test conditions are listed in Table IV.

BASIS OF COMPARISON

In this study the measure of nozzle influence on performance is variation of turbine efficiency over a span of off-design pressure ratios ("Range"; good range indicates small variation). Other measures such as hydraulic efficiency, nozzle coefficient, etc. could have been chosen. Although not always strictly correct because of small variations in per unit losses, efficiency is in most cases a valid index. It is usually plotted against velocity ratio ( $u/C_0$ ) but sometimes against other parameters.

RESULTS OF DIVERGENCE TESTS

The results of Phase I (divergence) testing are summarized in Figures 9 to 38.

$M_D = 2.5$  nozzle results are shown in Figures 9 to 13, 19-23, and 29-33. They show peak efficiency is maximized at divergence angles of 11° to 13° (half angle) with 11° predominating above design pressure ratio and 13° below. The difference is not great, however. This is illustrated clearly in the basic plots of Figures 9-13 and in the efficiency vs divergence cross plots of Figures 19 to 23.

Plots summarizing efficiency vs velocity ratio at pressure ratios above and below design for different nozzles (Figures 29 to 33) clearly show off-design efficiency trends and suggest range is best with either small (7°) or large (15°) half angles, dropping slightly in between. However, the peak efficiency of intermediate angles is significantly greater than the extremes and more than makes up a small deficiency in range.

The tests at design mach no. = 4.0 (for  $\gamma = 1.4$ ), shown in Figures 14 to 18, reveal no such optimum divergence. The performance of all nozzles is very similar; essentially independent of divergence on or off design. All curves of any given pressure ratio are closely bunched, and all efficiency vs divergence angle curves (Figures 24-28) are essentially flat, indicating no real optimum. The 7° nozzle shows some advantage in peak efficiency but this is slight and may not be significant. The summaries (Figures 34 to 38) indicate a similar conclusion; little variation in off-design performance from angle to angle. Though somewhat obscured by different losses it appears the range capability of the  $M_0 = 4.0$  nozzles is not so great as the mach 2.5's, at least not as good as the best ones.

The  $M_0 = 4.0$  nozzles were tested at a  $\Delta P$  ( $P_0 - P_e$ ) four times greater than the  $M_0 = 2.5$ 's and may account for some of the similarity in performance shown by all mach 4.0 nozzles.

#### PLUG NOZZLES

The results of Phase II tests are summarized in Figures 39 to 43. The two best conical nozzles are shown on the same plot for comparison. These tests, particularly plug nozzle C, show greater than average scatter, but the conclusions are obvious and not affected. Peak efficiency and range are inferior to all  $M_0 = 2.5$  conical nozzles tested. Direct comparison is valid here because test conditions were identical.

An interesting observation is that plug nozzles "B" (blunt plug) and "C" (half plug) exhibit a very low discharge coefficient of .60 to .63, suggesting severe contraction exists in this type design as in sharp edged orifices.

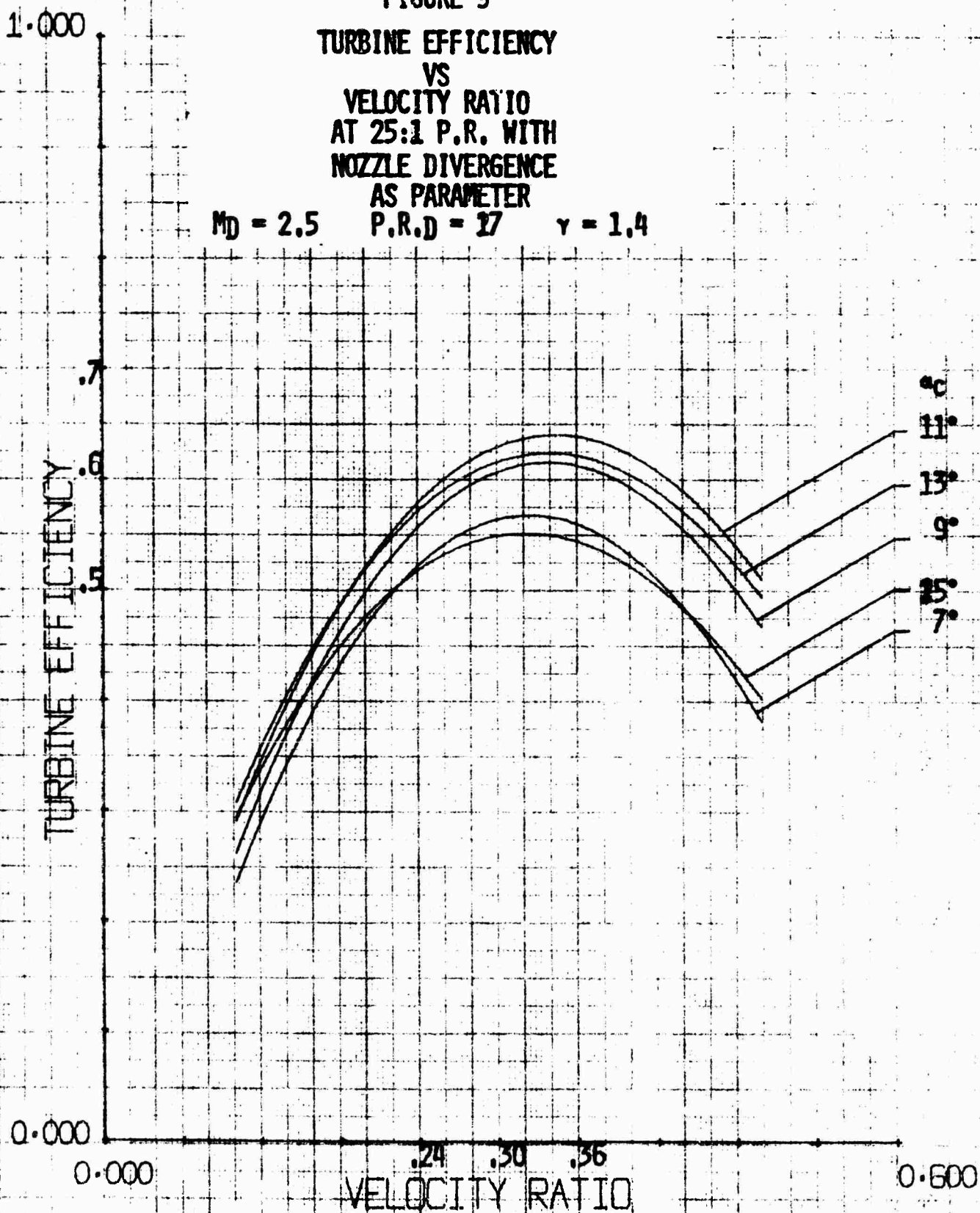
#### SPECIFIC HEAT RATIO

The results of Phase III (specific heat) tests are summarized in Figures 44 and 45. Figure 44 shows performance with 11° half angle and specific heat ratios from 1.18 (Freon 12) to 1.68 (Argon), with each at its own design condition. It suggests a maximum in efficiency occurs, probably at  $\gamma = 1.4$ , with efficiency dropping off above and below. The Argon and Nitrogen summary plots (Figures 45 and 31) show substantially better range for the Argon ( $\gamma = 1.68$ ) than Nitrogen ( $\gamma = 1.4$ ), suggesting that off-design performance improves with increased specific heat ratio. Peak efficiency is less in most cases although not enough to overcome the range advantage shown by the higher specific heat ratio gas.

FIGURE 9

TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 25:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_D = 2.5$   $P.R.D = 27$   $\gamma = 1.4$

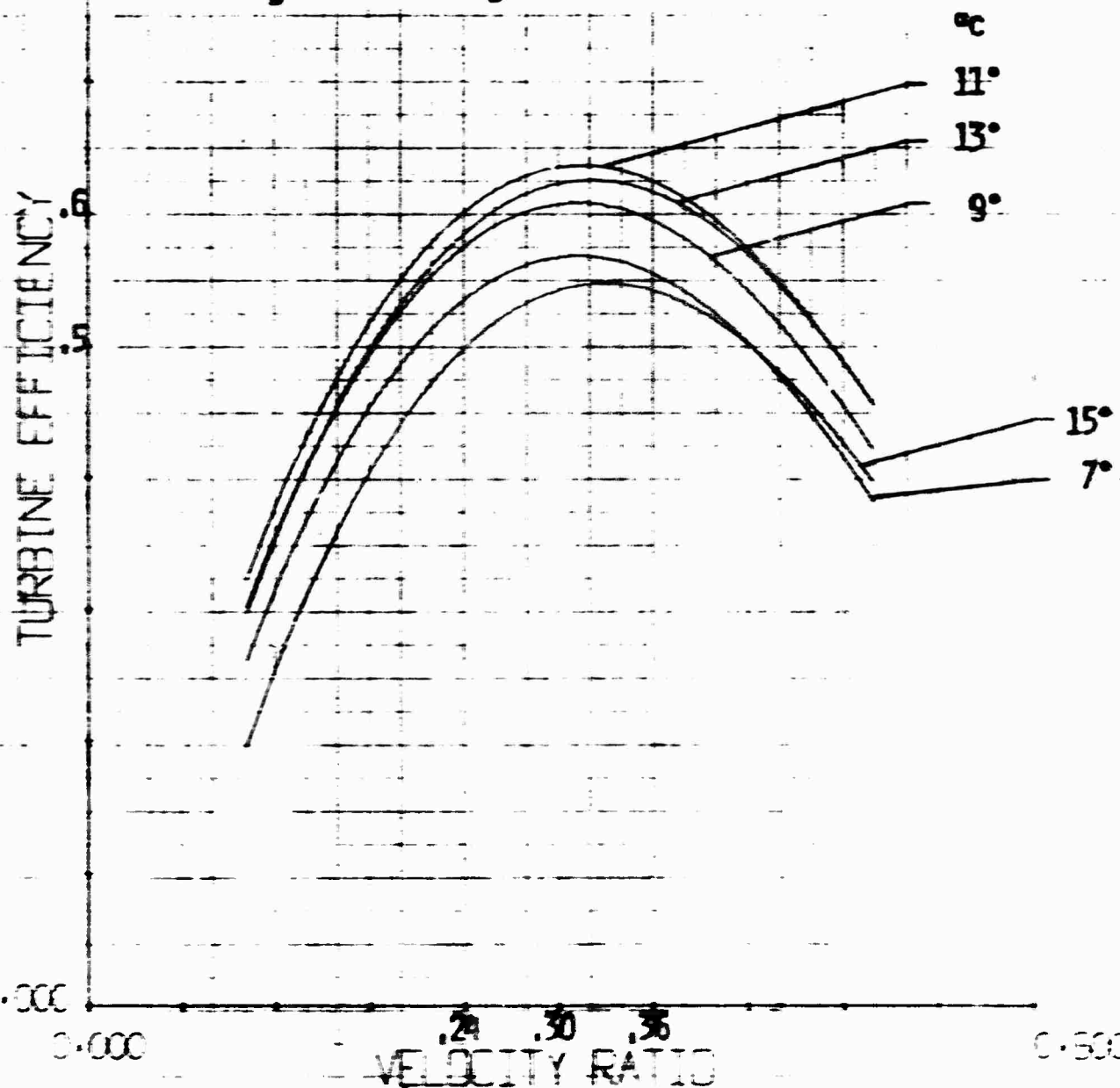


SUMMARY PLOT, MACH 2.5, PR. RATIO = 25.

1.000

FIGURE 10  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 20:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_0 = 2.5$  P.R.D = 17  $\gamma = 1.4$



SUMMARY PLOT, MACH 2.5, PR. RATIO = 20:



1.000

FIGURE 11  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 17:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_D = 2.5$   $P.R._D = 17$   $\gamma = 1.4$

TURBINE EFFICIENCY

0.000

0.000

VELOCITY RATIO

0.600

°  
18°  
11°  
9°  
15°  
7°

SUMMARY PLOT, MACH 2.5, P.R. RATIO = 17

1.000

FIGURE 12  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 15:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_0 = 2.5$      $P.R.D = 17$      $\gamma = 1.4$

TURBINE EFFICIENCY

0.000

0.000

VELOCITY RATIO

$\alpha_c$

13°

11°

9°

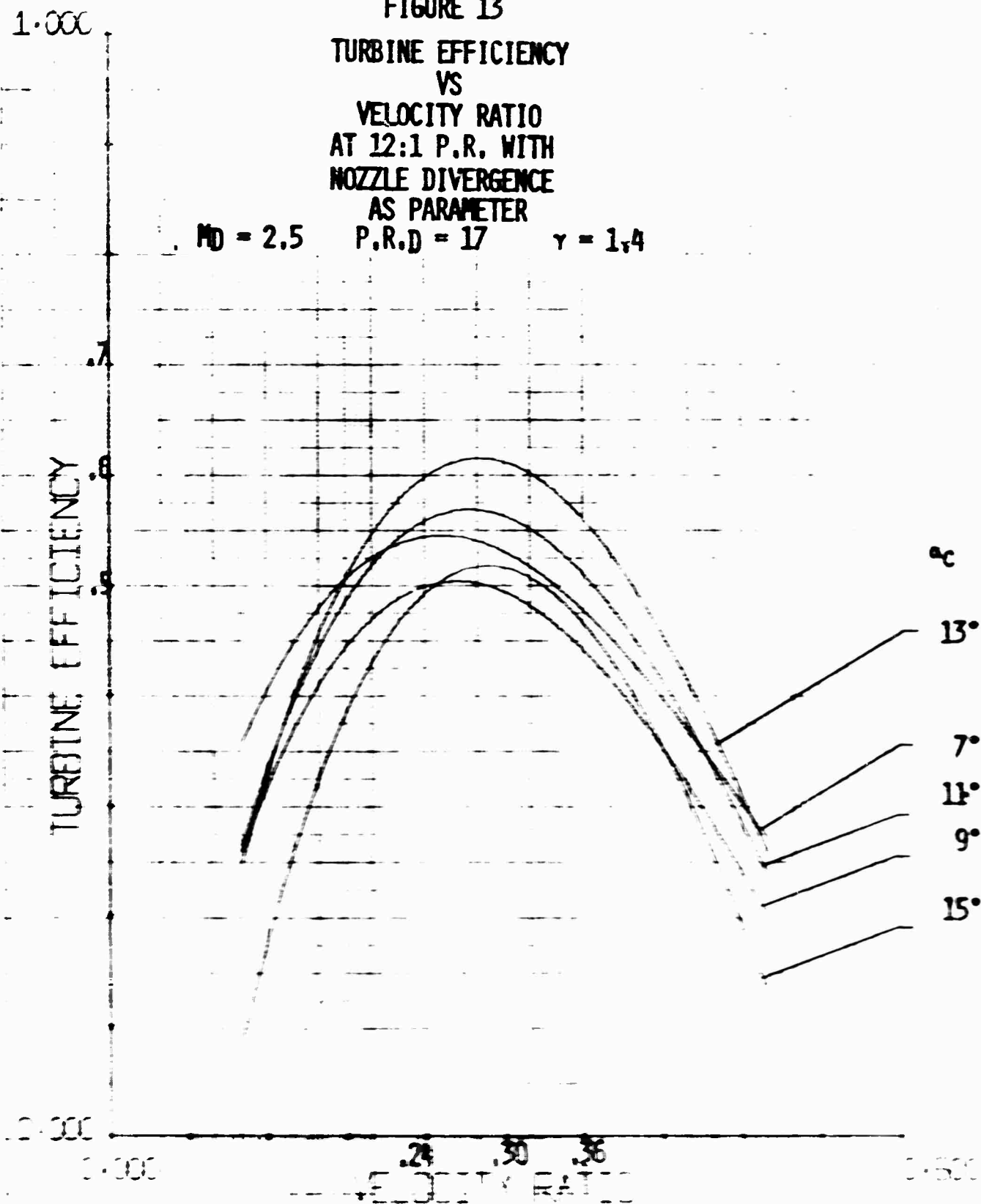
7°

15°

SUMMARY PLOT, MACH 2.5, P.R. RATIO = 15,

FIGURE 13  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 12:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_0 = 2.5$      $P.R.D = 17$      $\gamma = 1.4$



SUMMARY PLOT, MACH 2.5, P.R. = 12:1

1.000

FIGURE 14  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 200:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_0 = 4.0$      $P.R.D = 150$      $\gamma = 1.40$

TURBINE EFFICIENCY

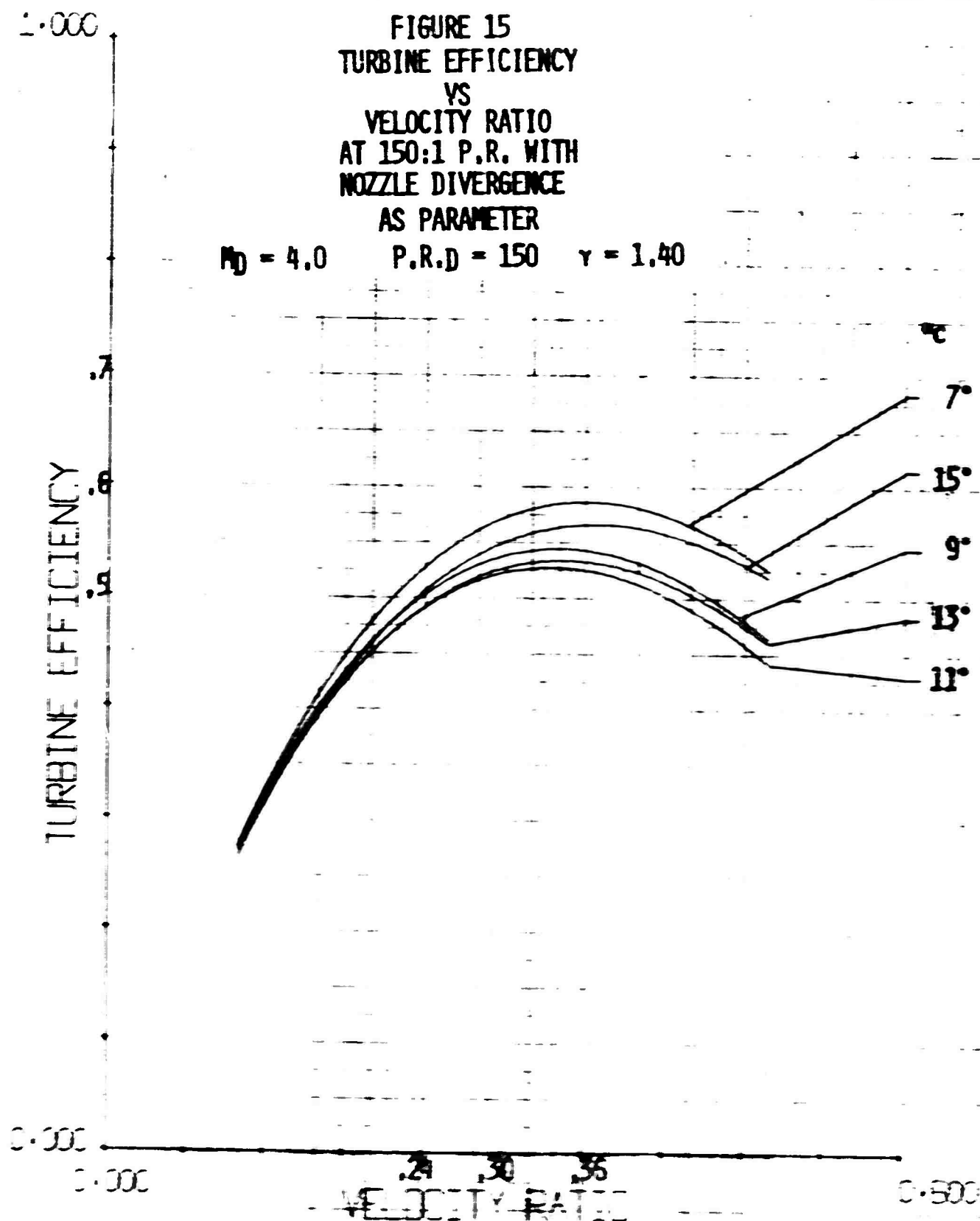
$\alpha_c$   
7°  
15°  
9°  
13°  
11°

0.000

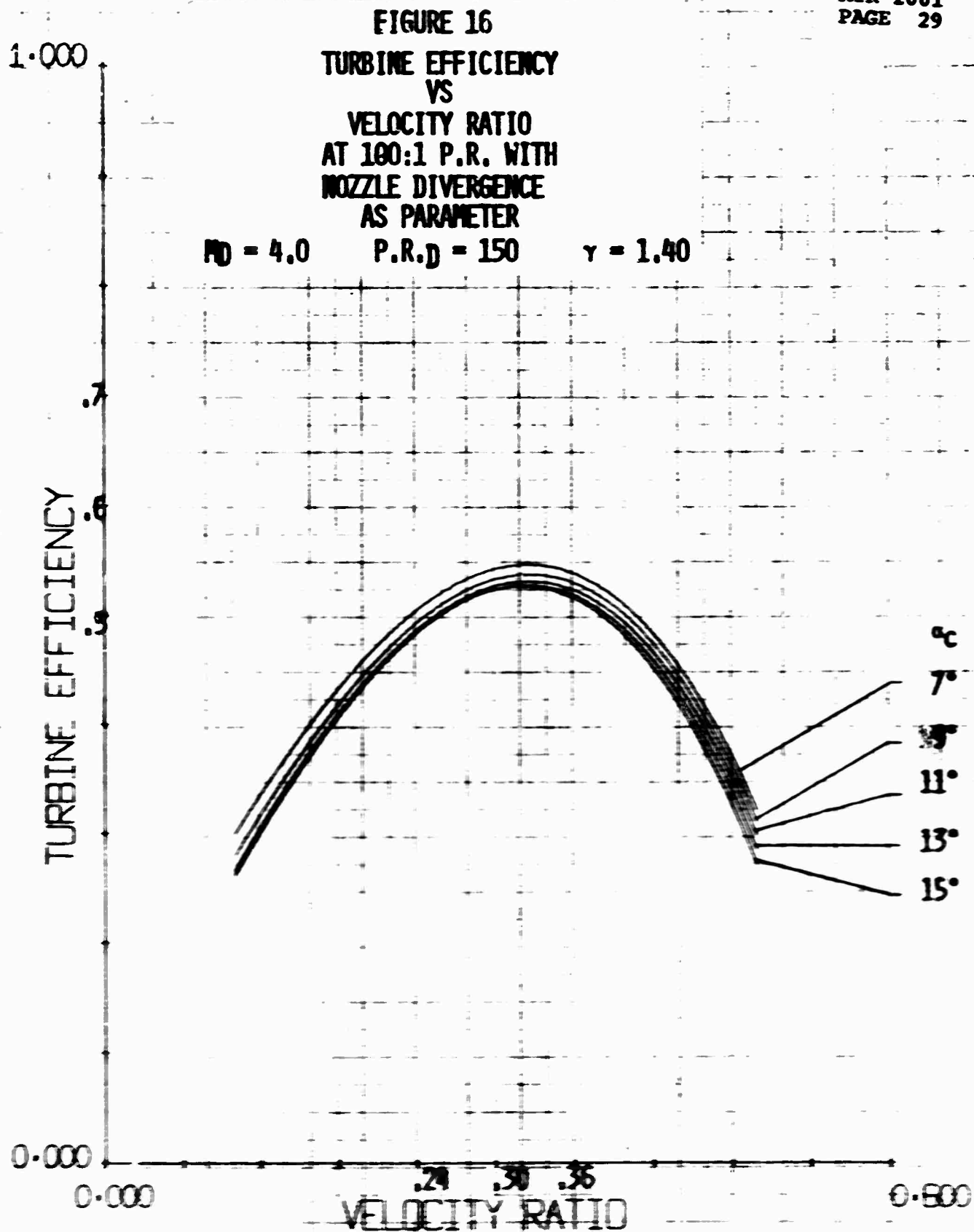
24 30 36  
VELOCITY RATIO

0.600

SUMMARY PLOT:  $M_0 = 4.0$ ; P.R. RATIO = 200:



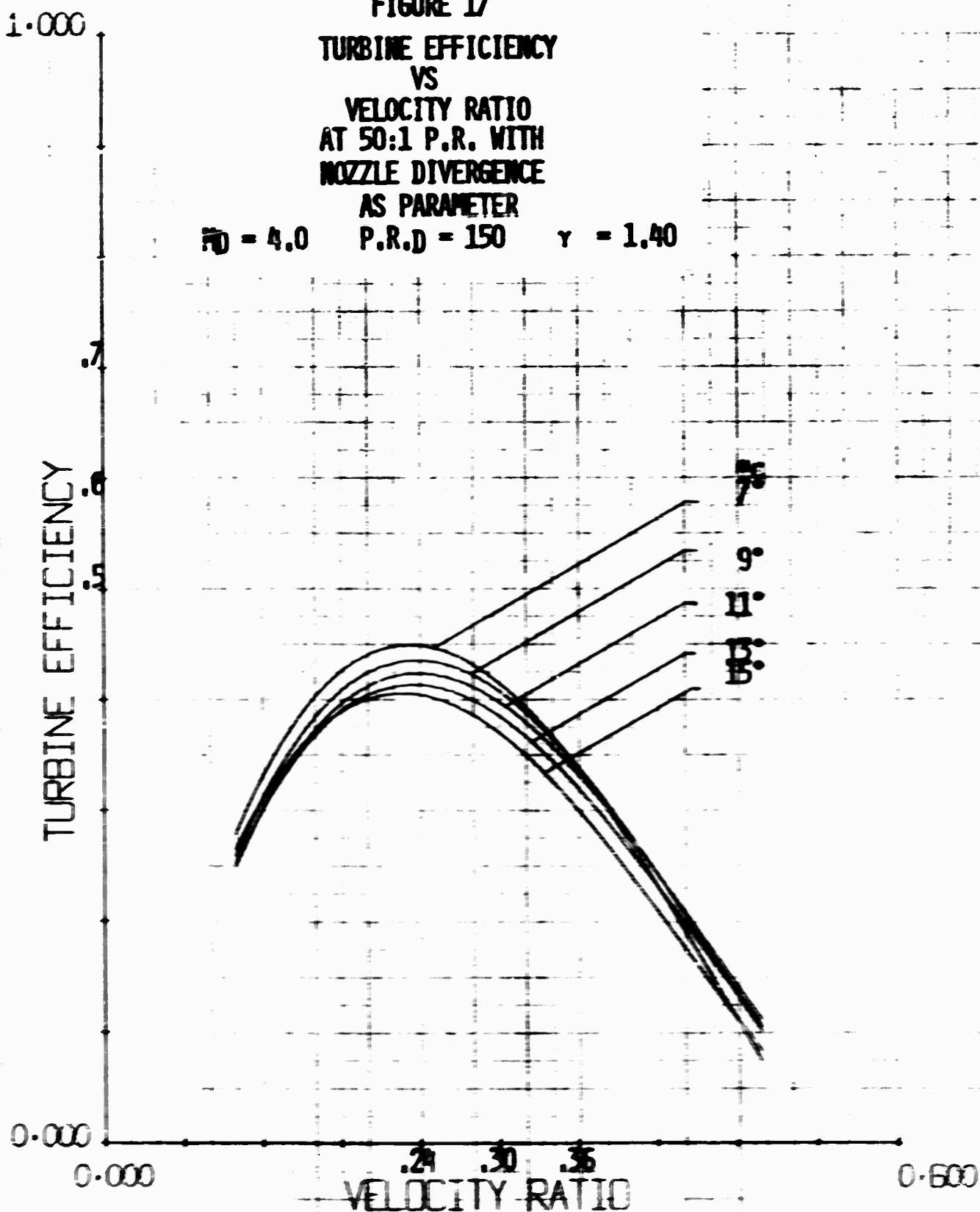
SUMMARY PLOT, MACH 4.0, P.R. RATIO=150.



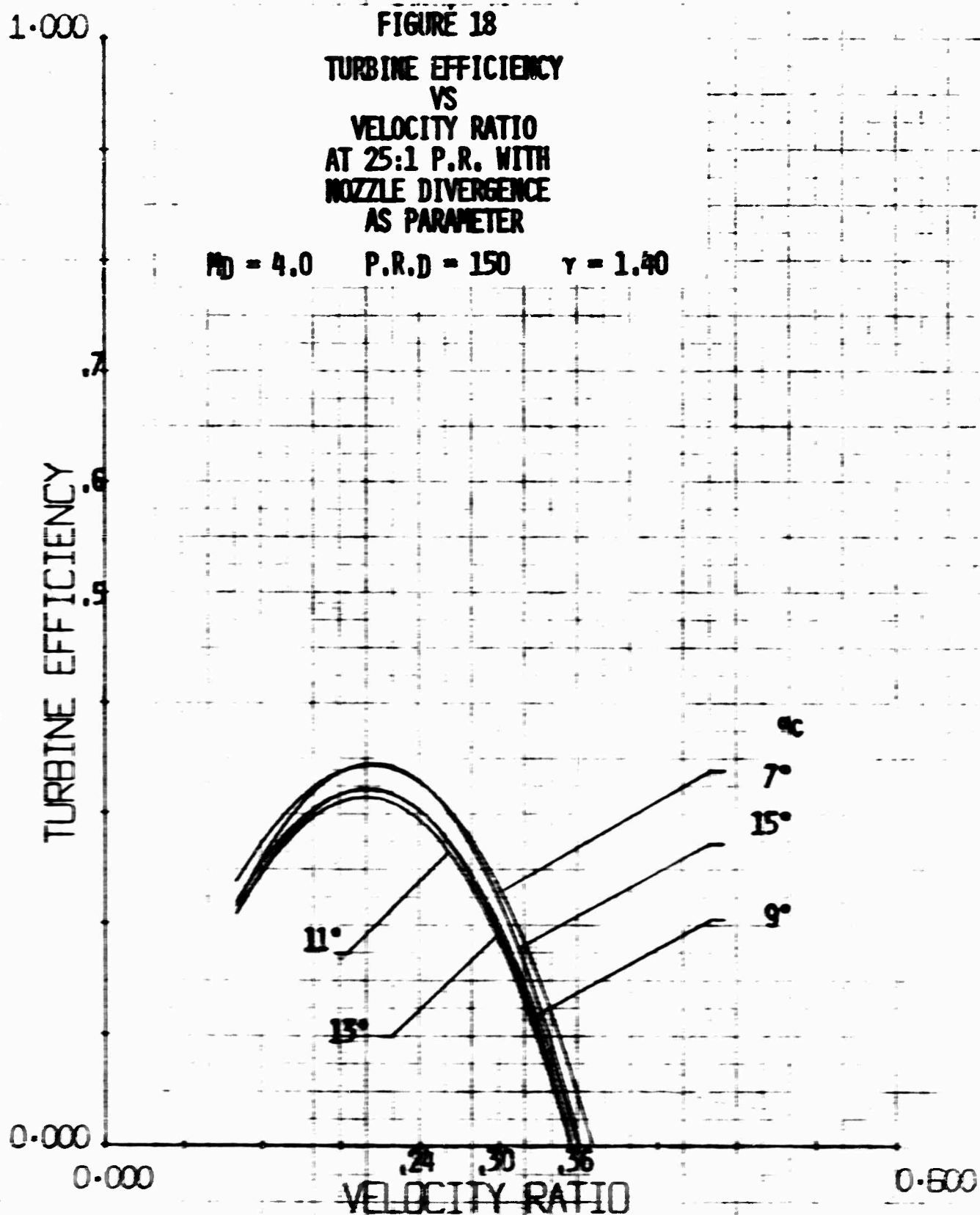
SUMMARY PLOT, MACH 4.0, PR. RATIO=100.

FIGURE 17  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
AT 50:1 P.R. WITH  
NOZZLE DIVERGENCE  
AS PARAMETER

$M_0 = 4.0$     $P.R.D = 150$     $\gamma = 1.40$



SUMMARY PLOT, MACH 4.0, P.R. RATIO=50.

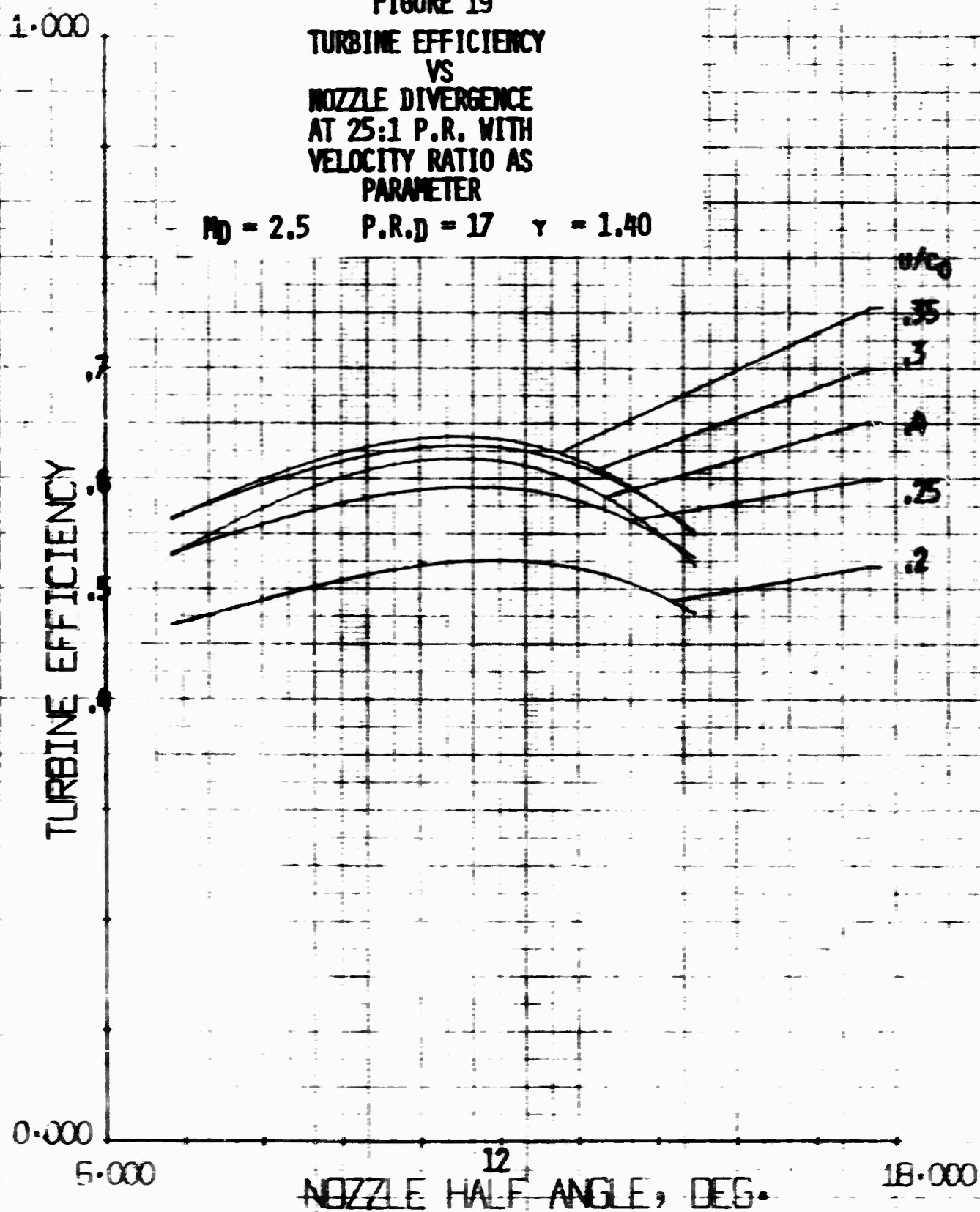


SUMMARY PLOT, MACH 4.0, PR. RATIO=25.

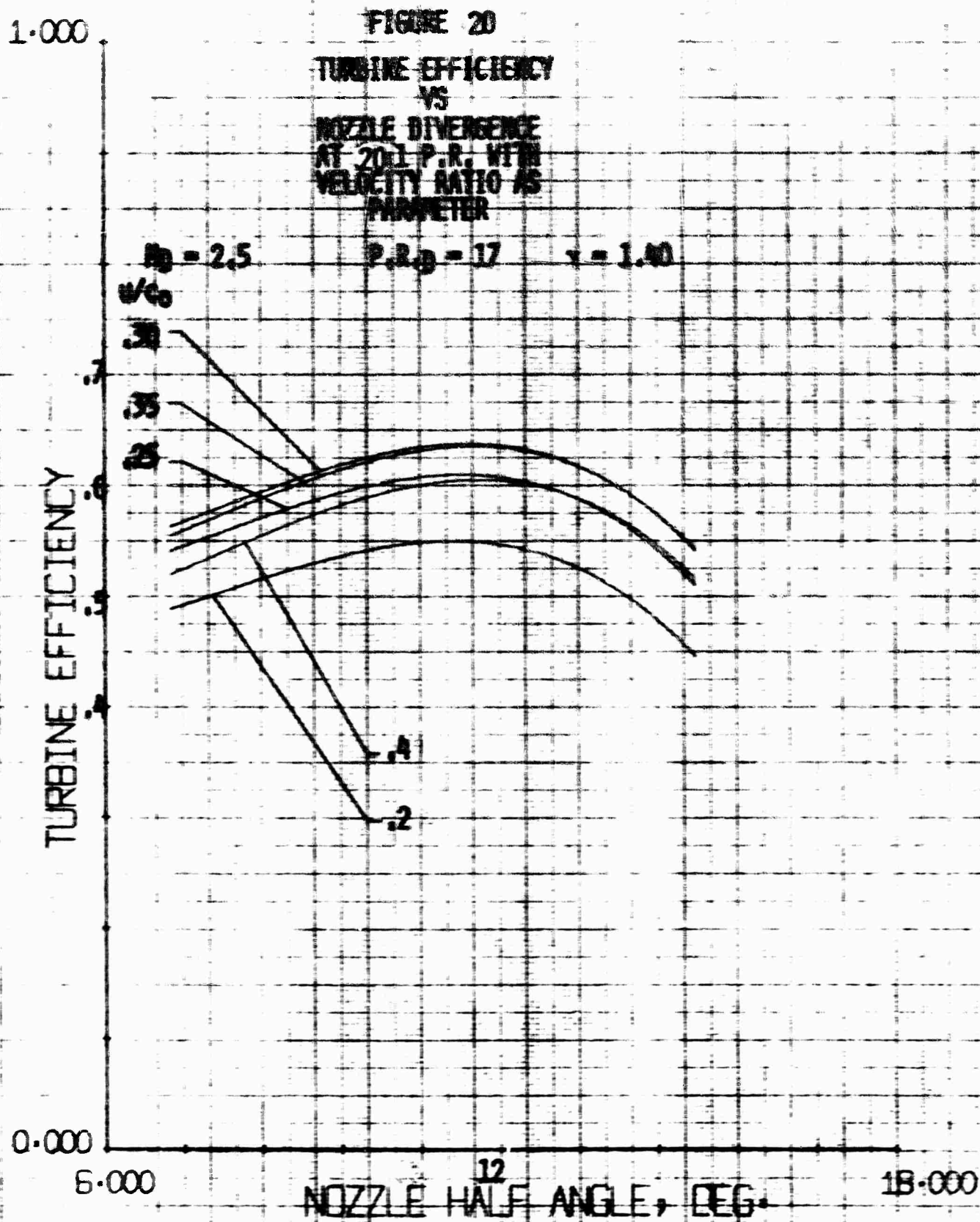


FIGURE 19  
TURBINE EFFICIENCY  
VS  
NOZZLE DIVERGENCE  
AT 25:1 P.R. WITH  
VELOCITY RATIO AS  
PARAMETER

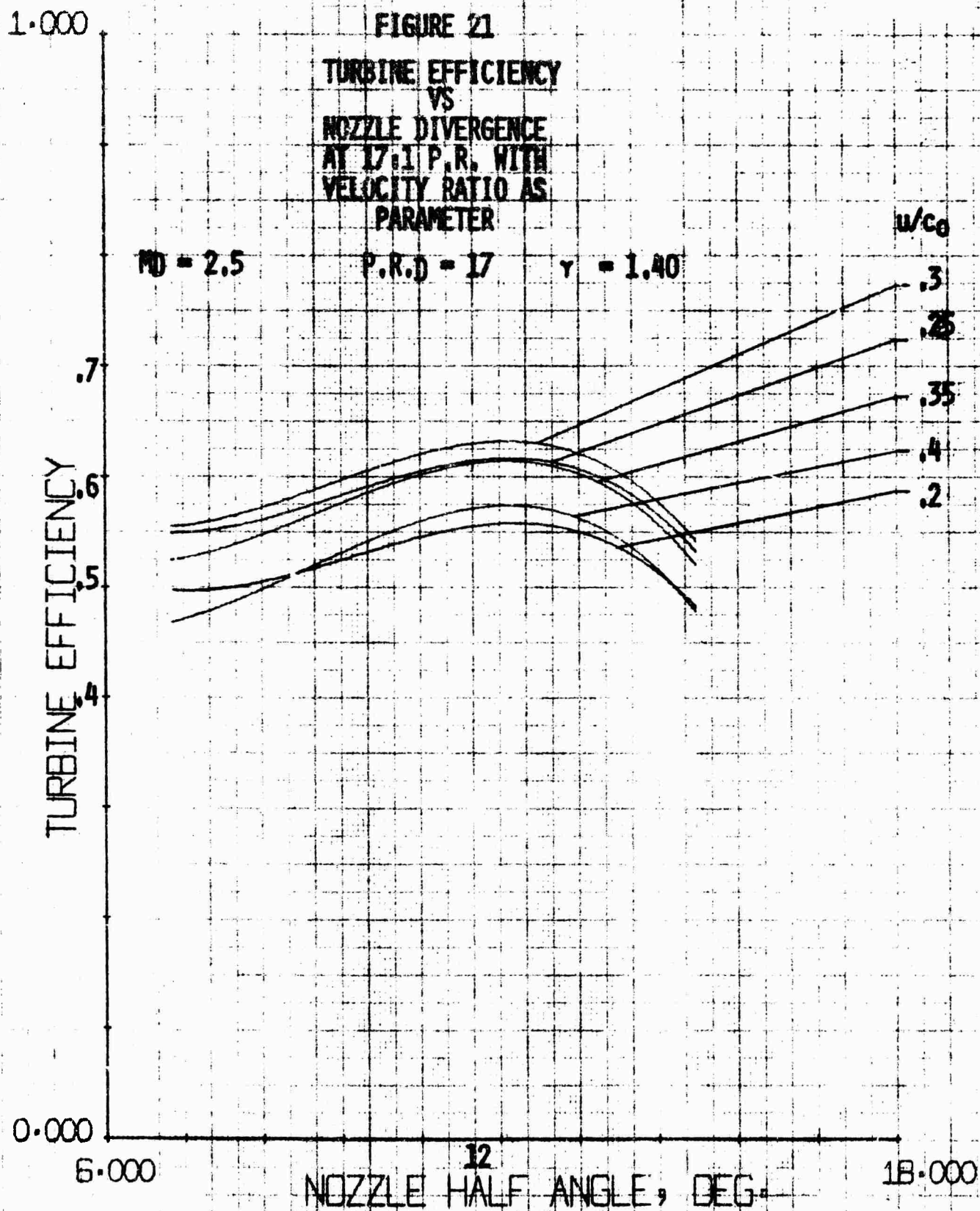
$M_D = 2.5$   $P.R.D = 17$   $\gamma = 1.40$



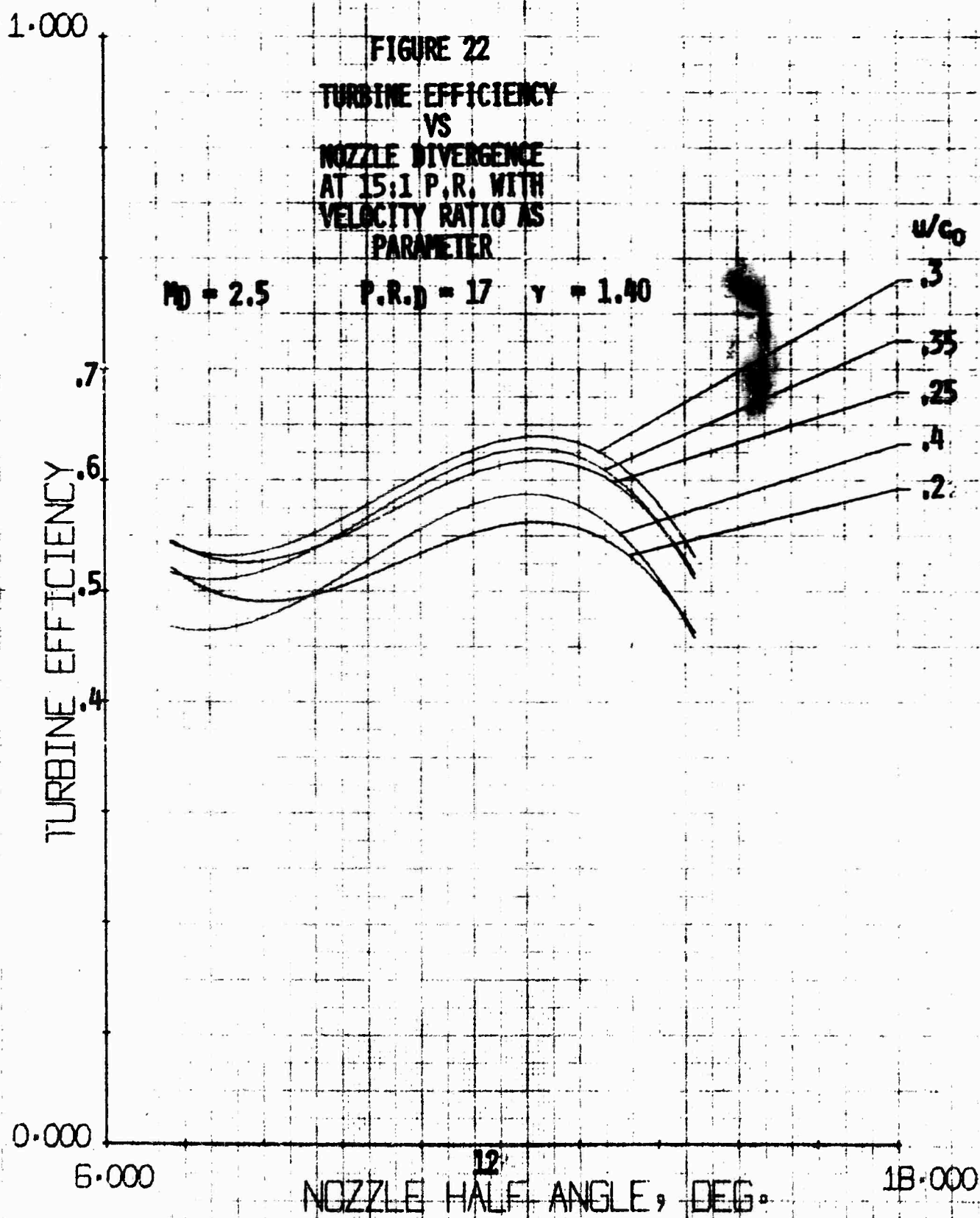
MACH 2.5 NOZZLES, PRESSURE RATIO=25.



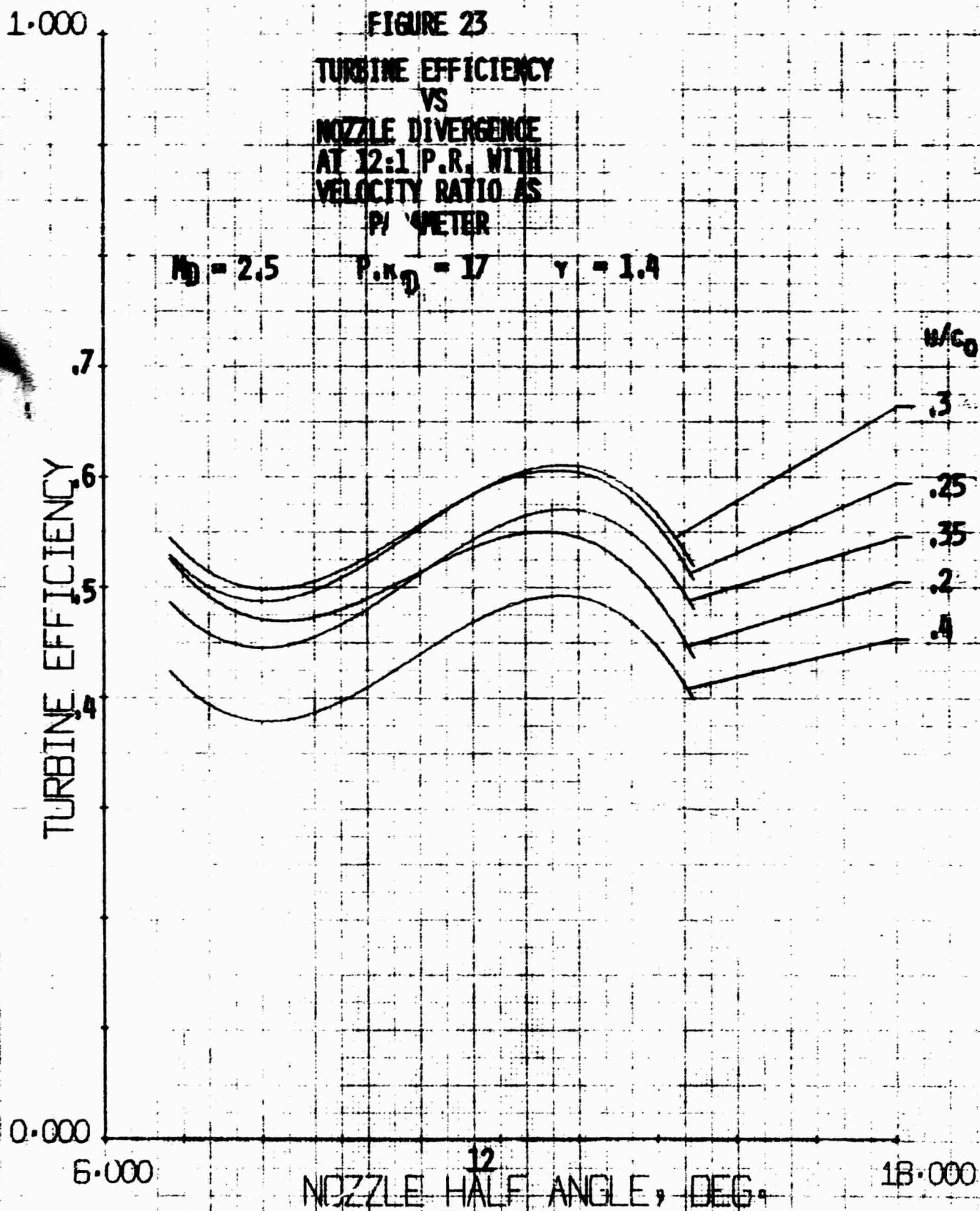
MACH 2.5 NOZZLES, PRESSURE RATIO=20.



MACH 2.5 NOZZLES, PRESSURE RATIO=17.

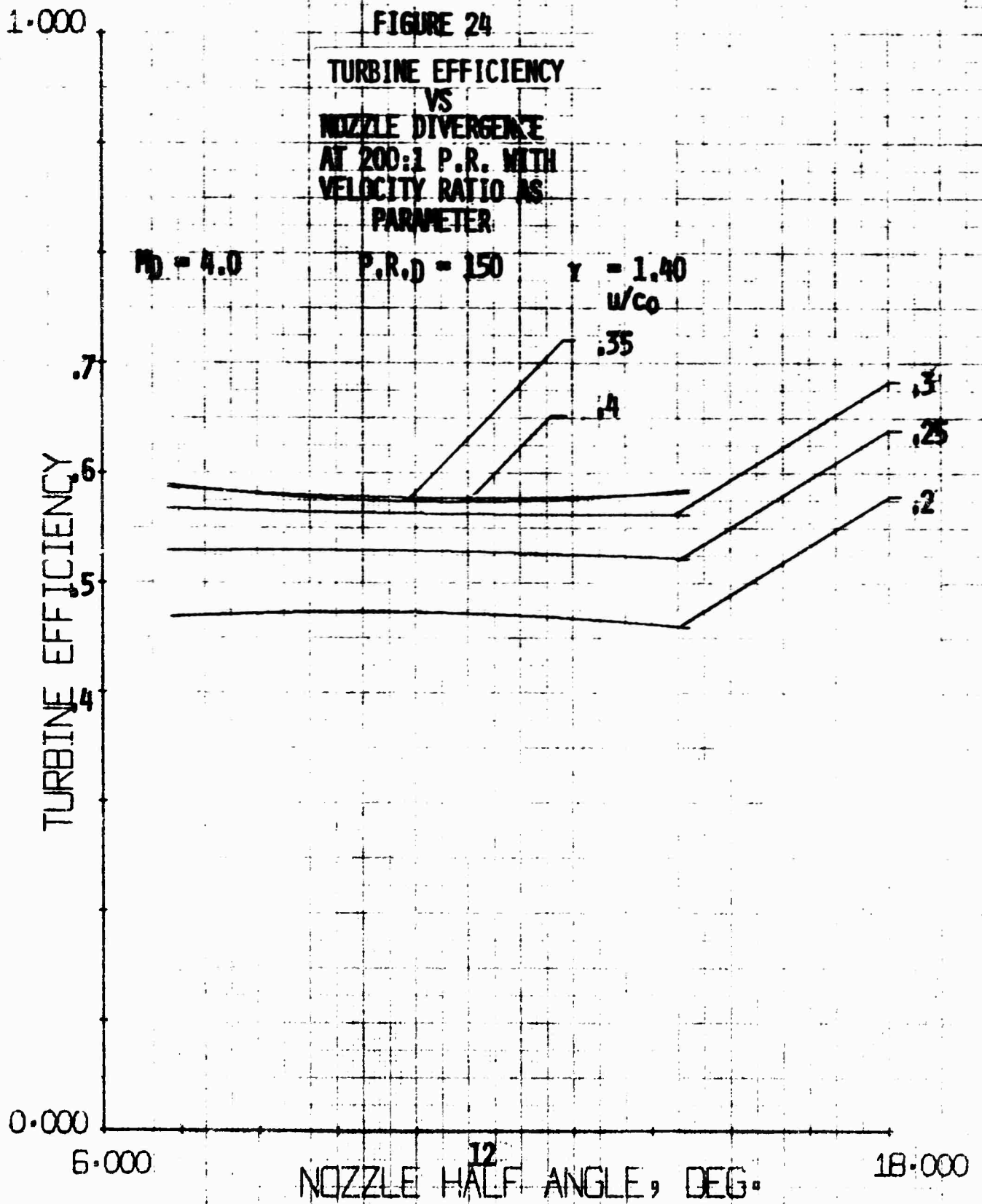


MACH 2.5 NOZZLES, PRESSURE RATIO=15.

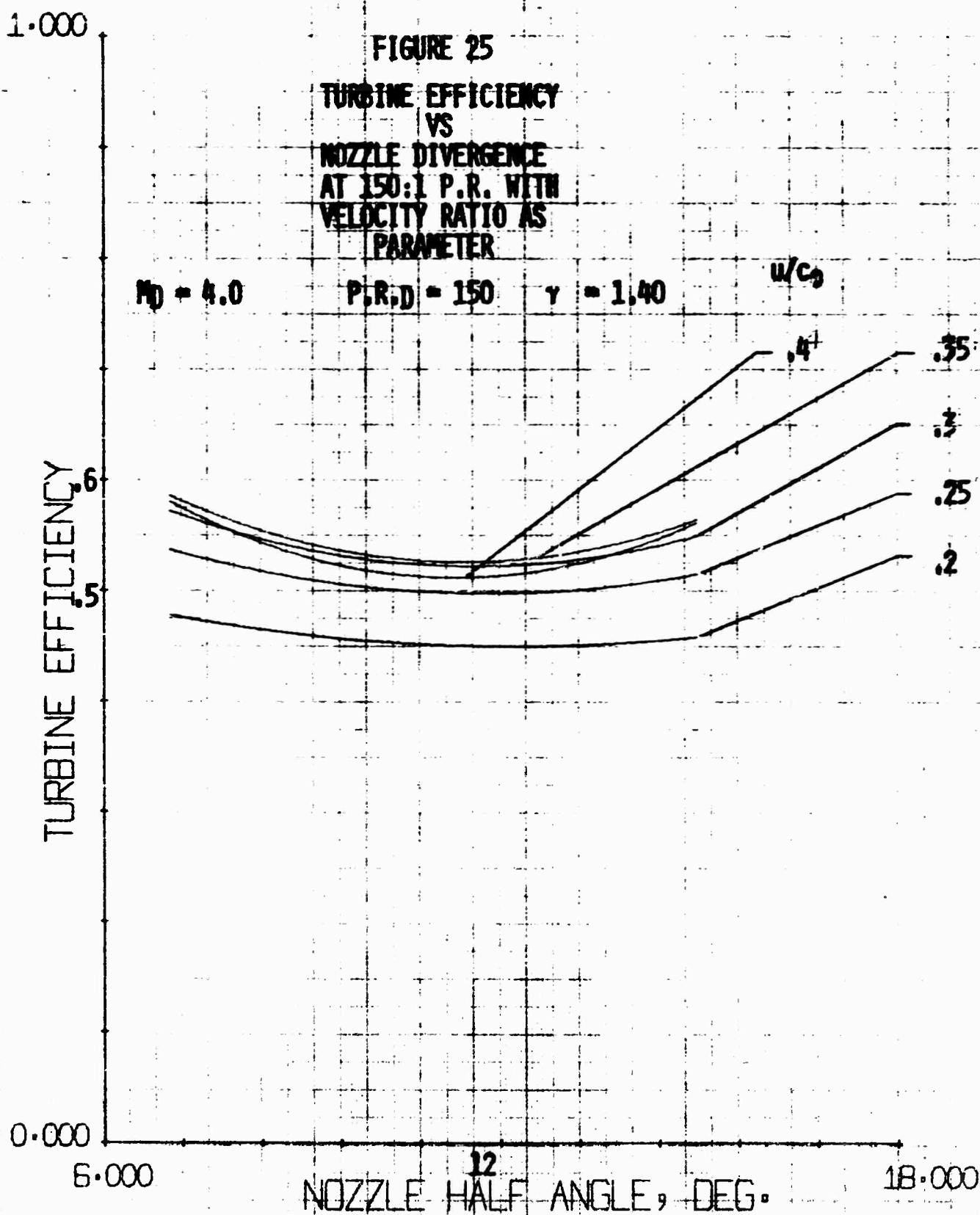


MACH 2.5 NOZZLES, PRESSURE RATIO=12.

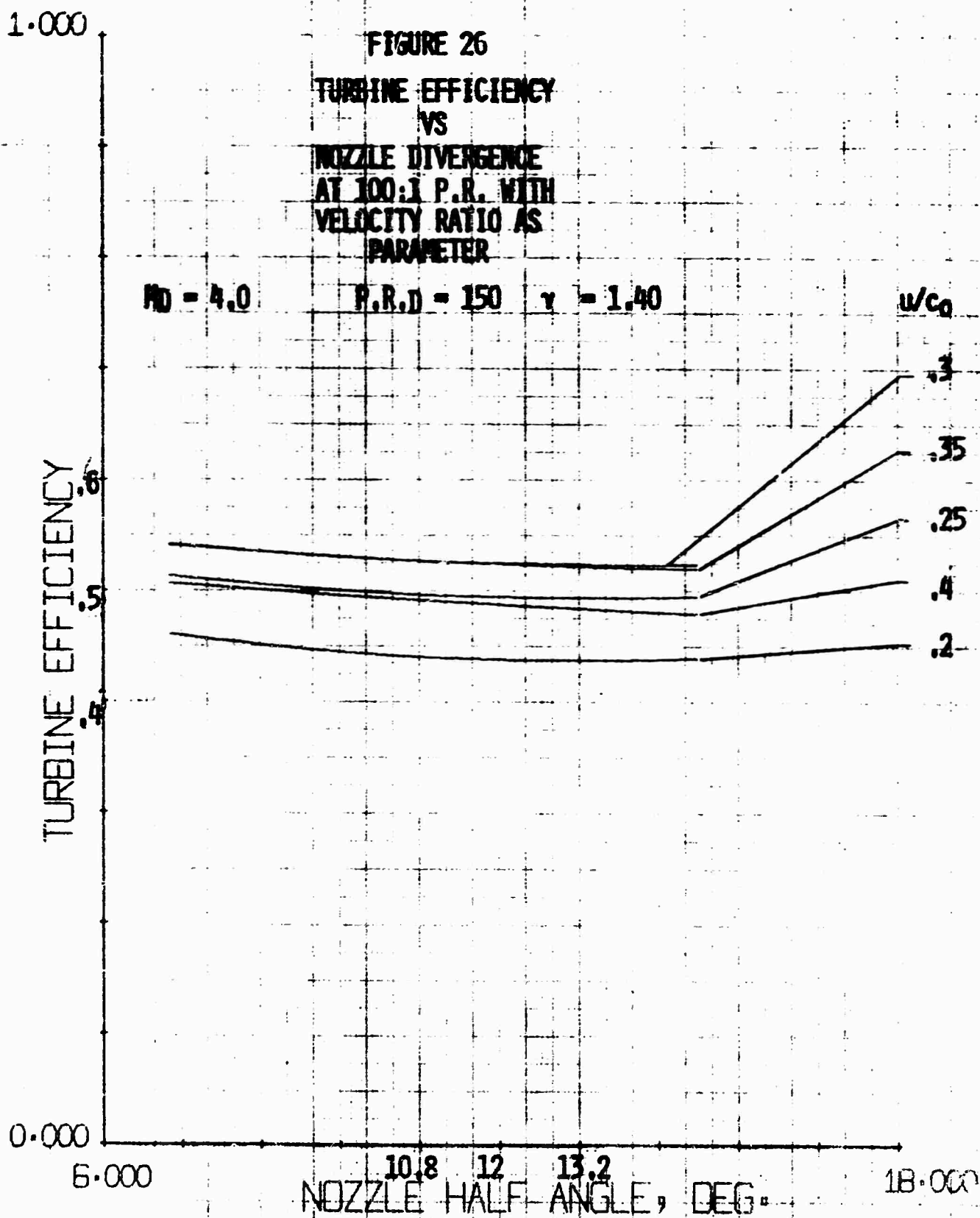




MACH 4.0 NOZZLES, PRESSURE RATIO=200.



MACH 4.0 NOZZLES, PRESSURE RATIO=150.



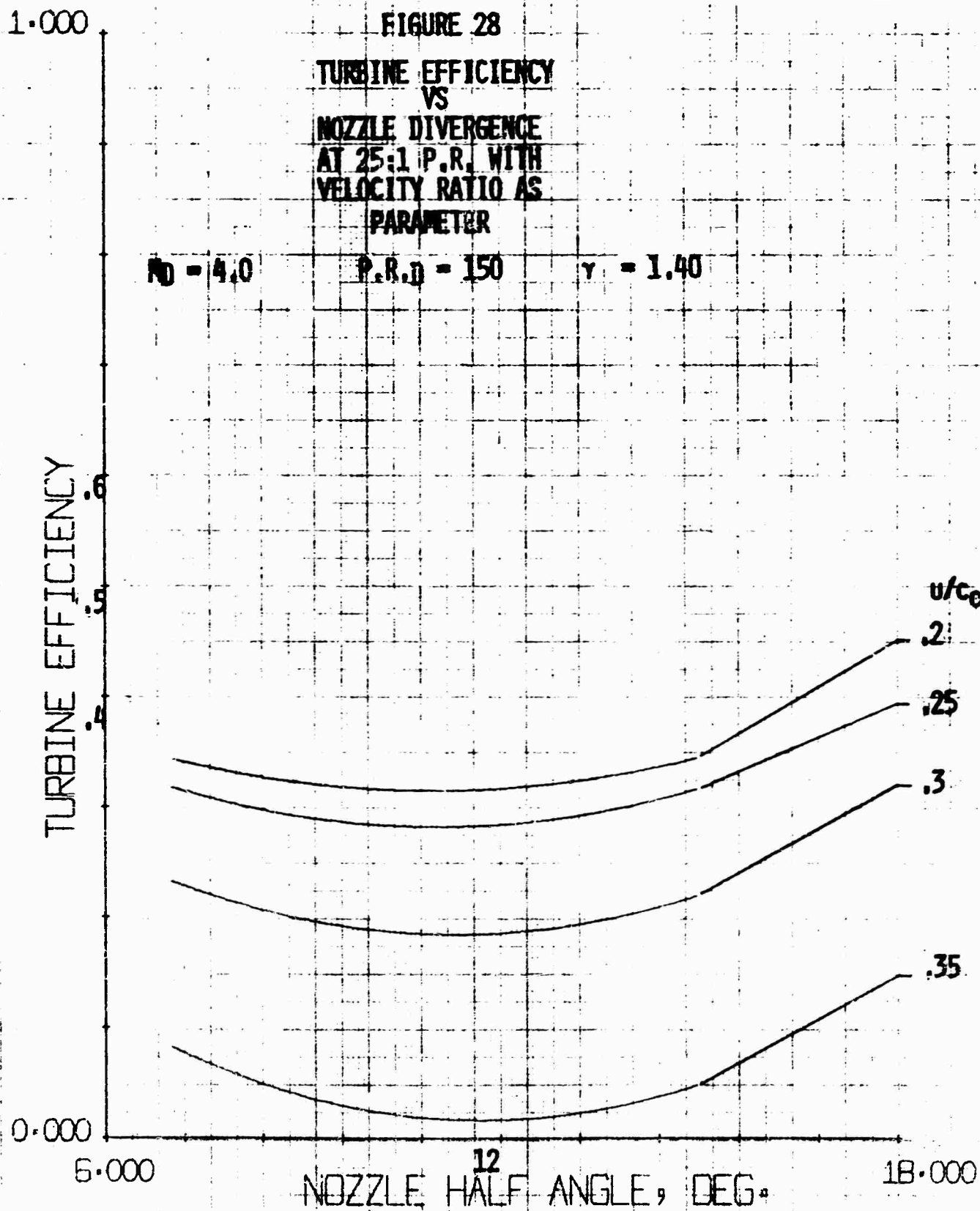
MACH 4.0 NOZZLES, PRESSURE RATIO=100



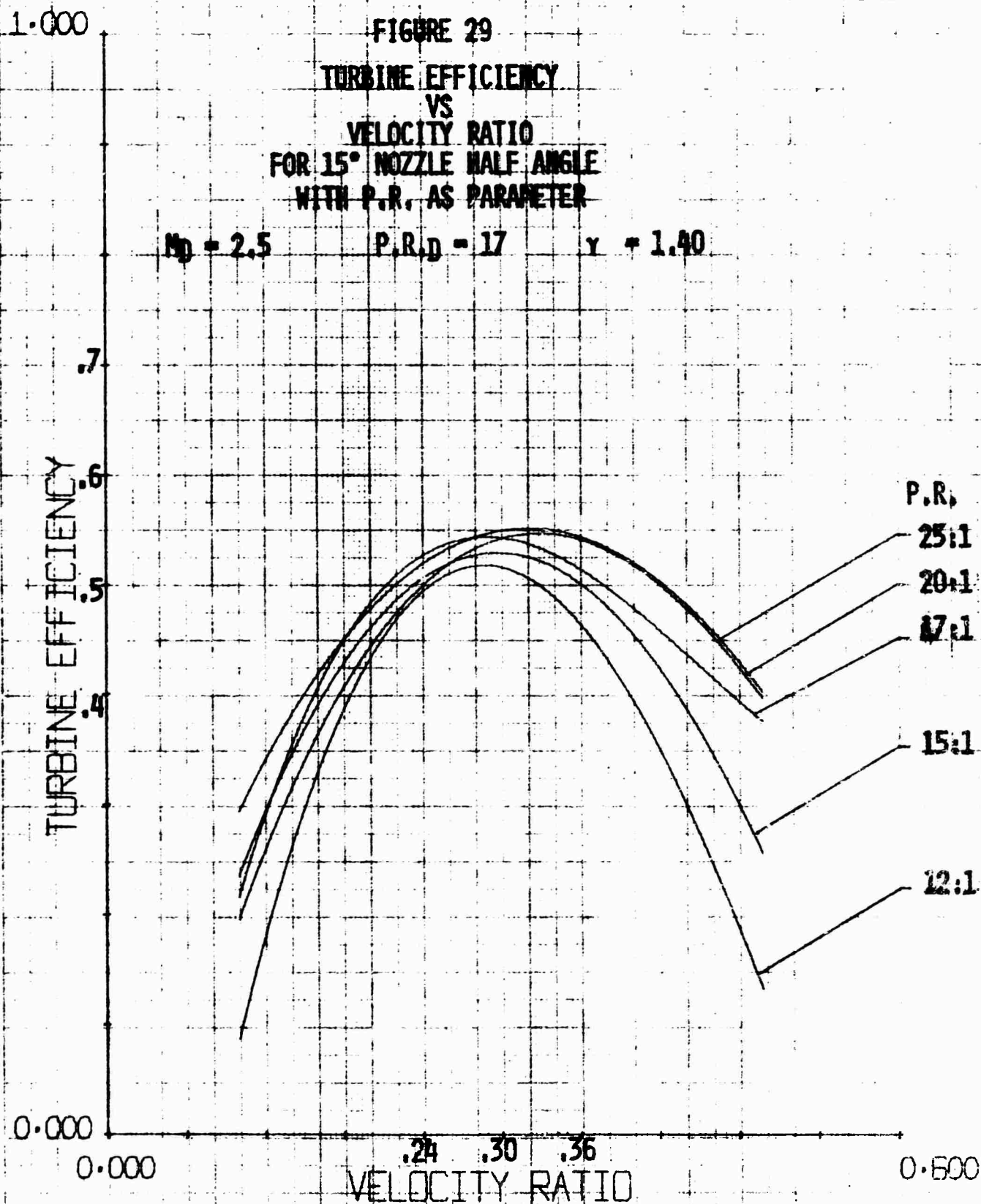
# NOZZLE DIVERGENCE AT 50:1 P.R. WITH VELOCITY RATIO AS PARAMETER

 $\gamma = 1.40$ 

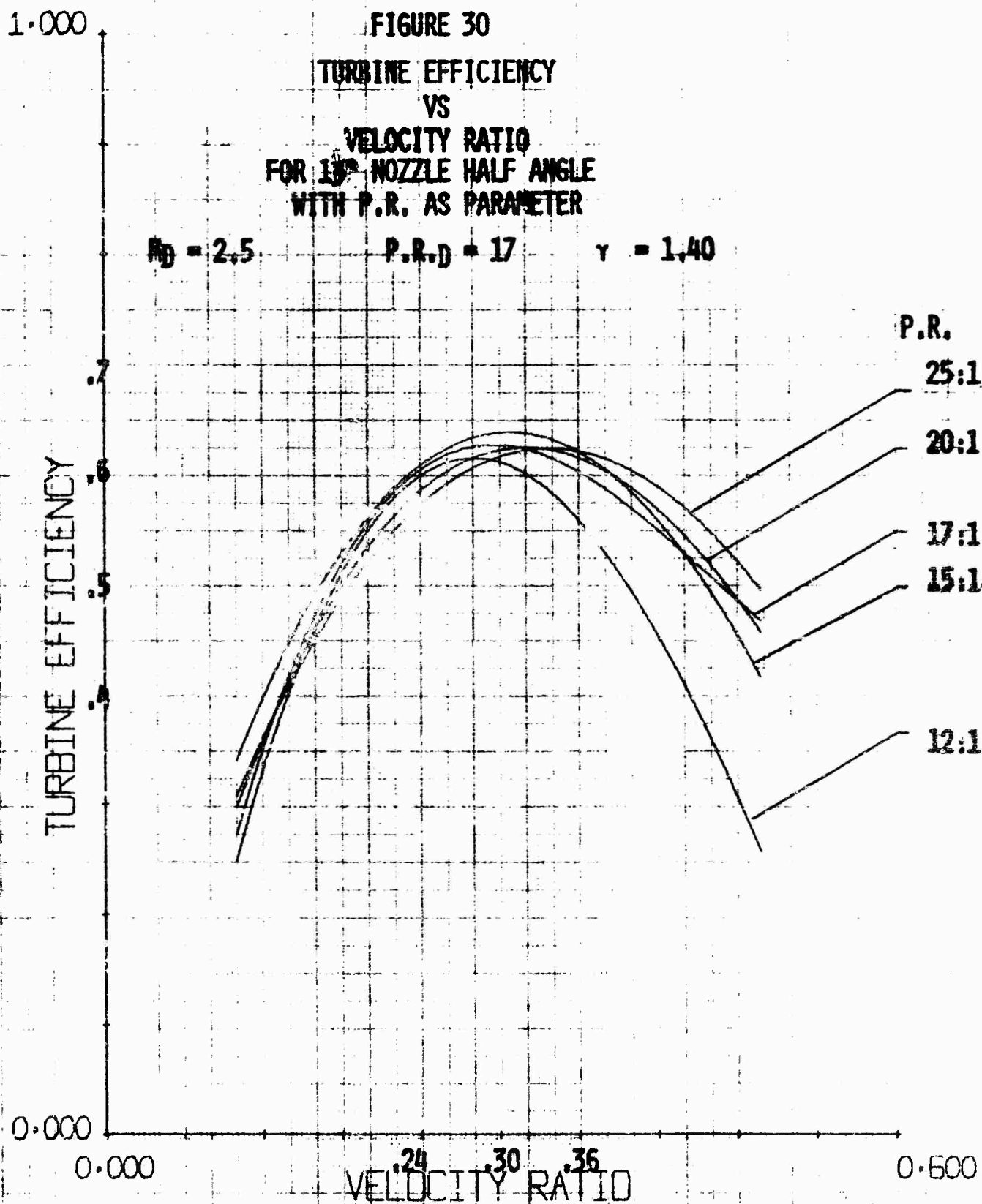
MACH 4.0 NOZZLES, PRESSURE RATIO=50.



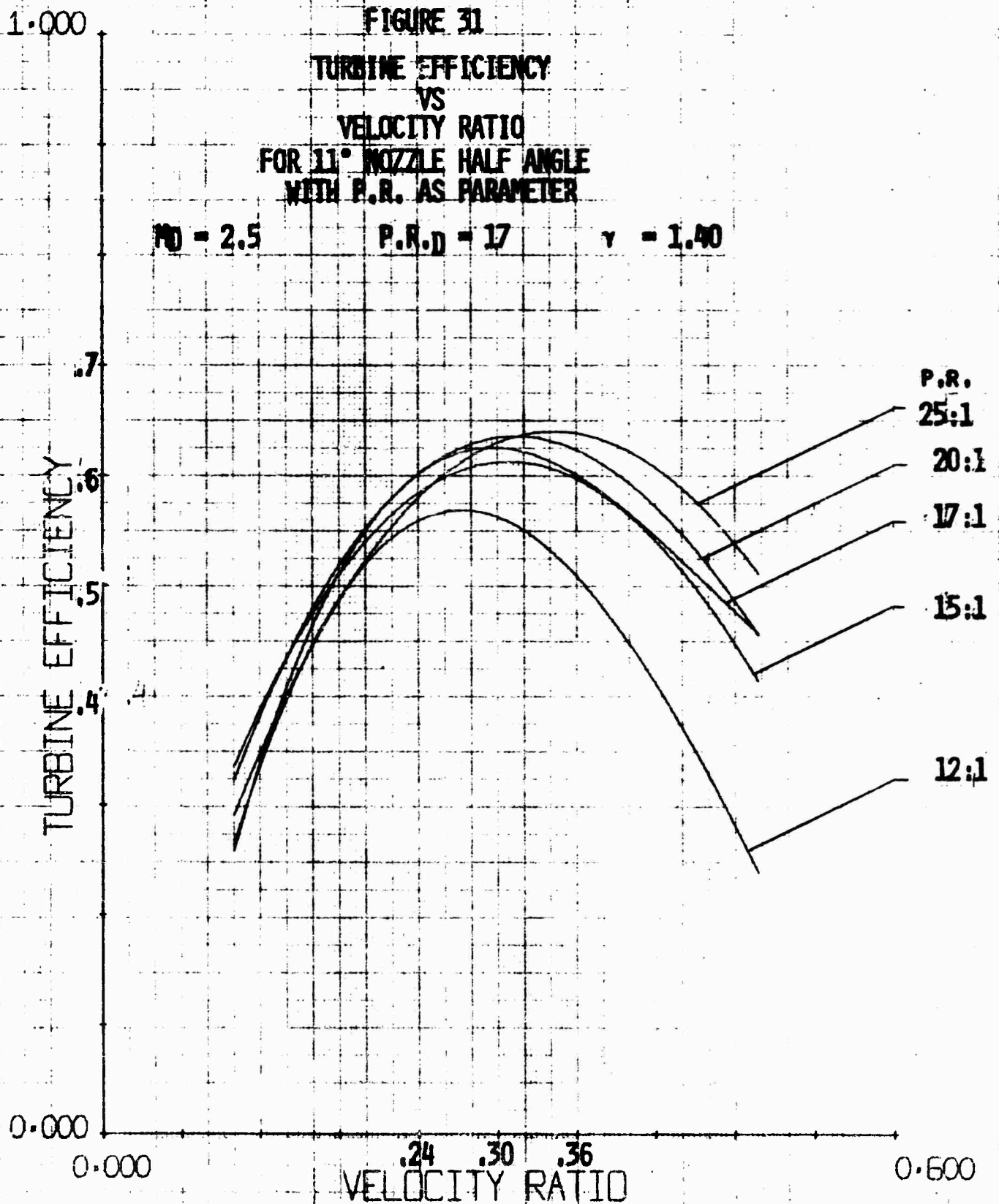
MACH 4.0 NOZZLES, PRESSURE RATIO=25.



SUMMARY PLOT, MACH 2.5, HALF ANGLE=15



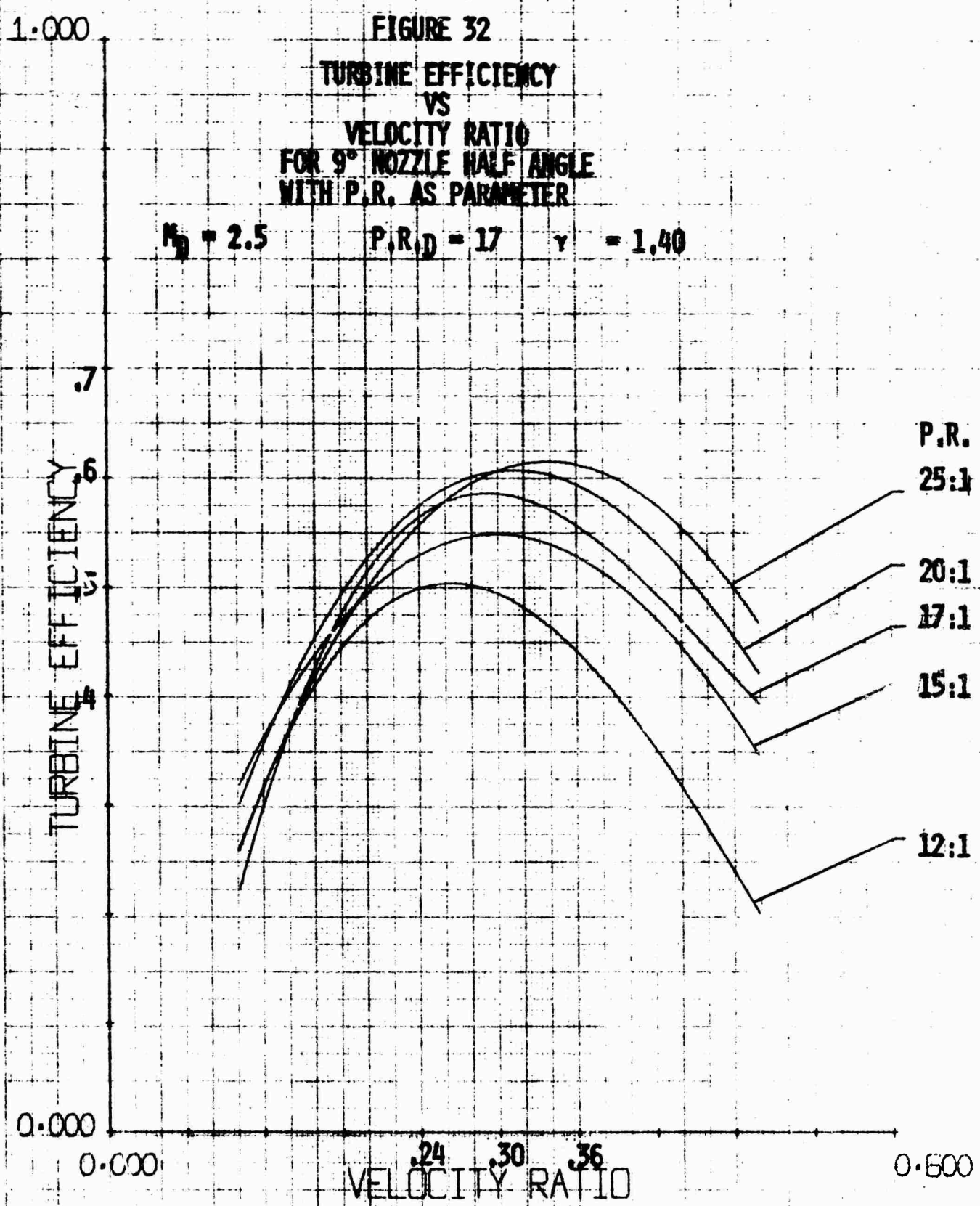
SUMMARY PLOT, MACH 2.5, HALF ANGLE=13



SUMMARY PLOT, MACH 2.5, HALF ANGLE=11

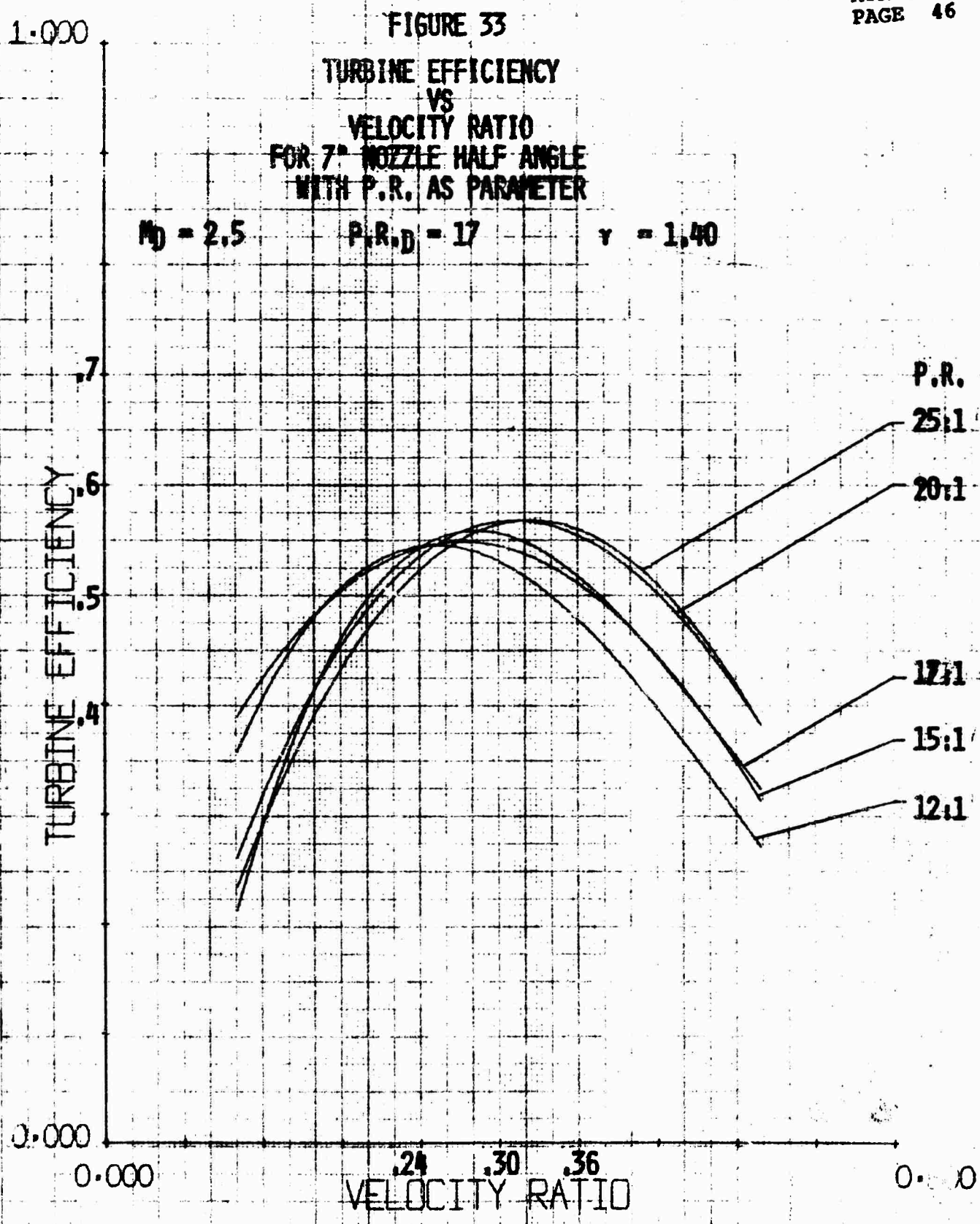
FIGURE 32  
TURBINE EFFICIENCY  
VS  
VELOCITY RATIO  
FOR 9° NOZZLE HALF ANGLE  
WITH P.R. AS PARAMETER

$M_0 = 2.5$        $P.R.D = 17$        $\gamma = 1.40$

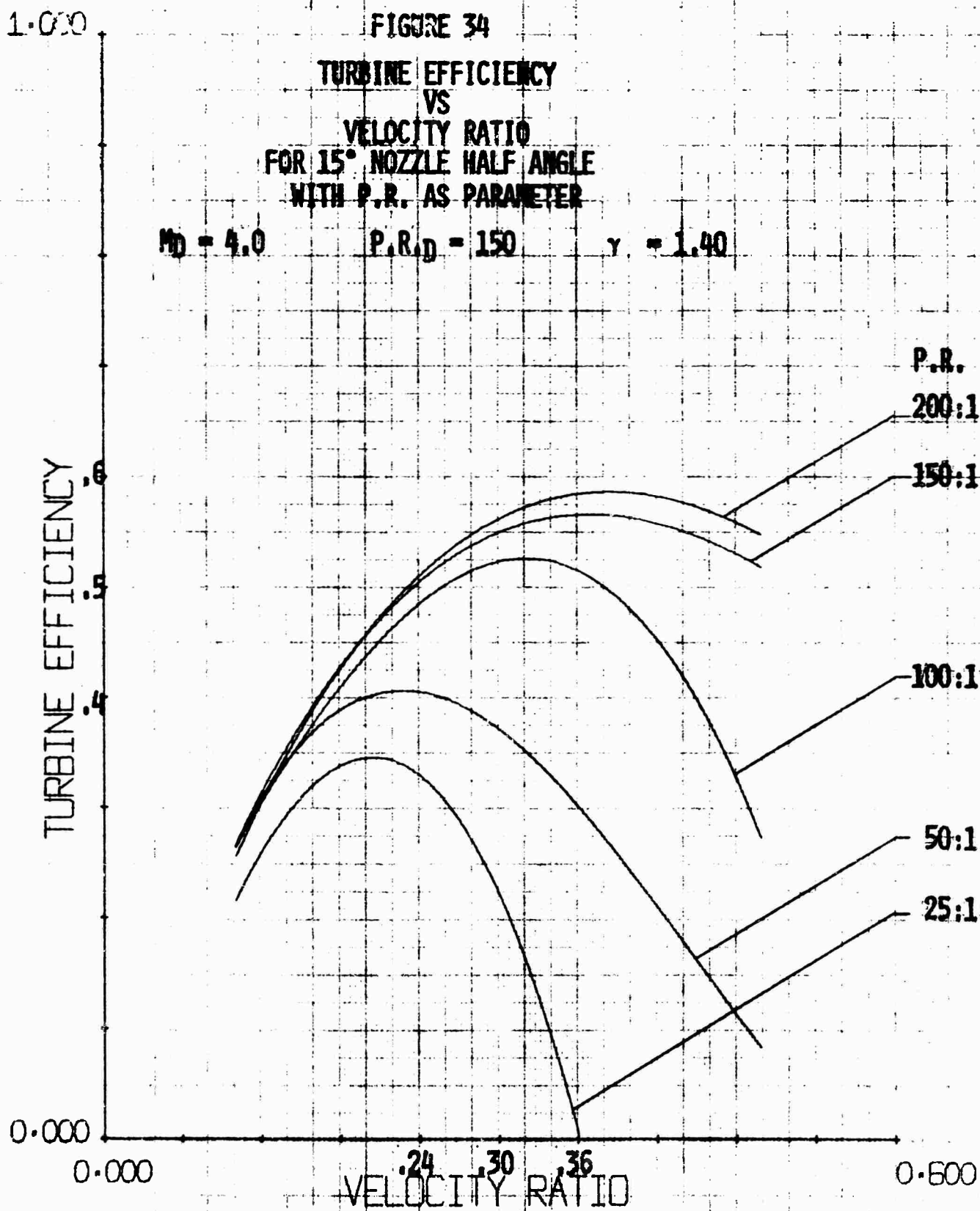


SUMMARY PLOT, MACH 2.5, HALF ANGLE = 9



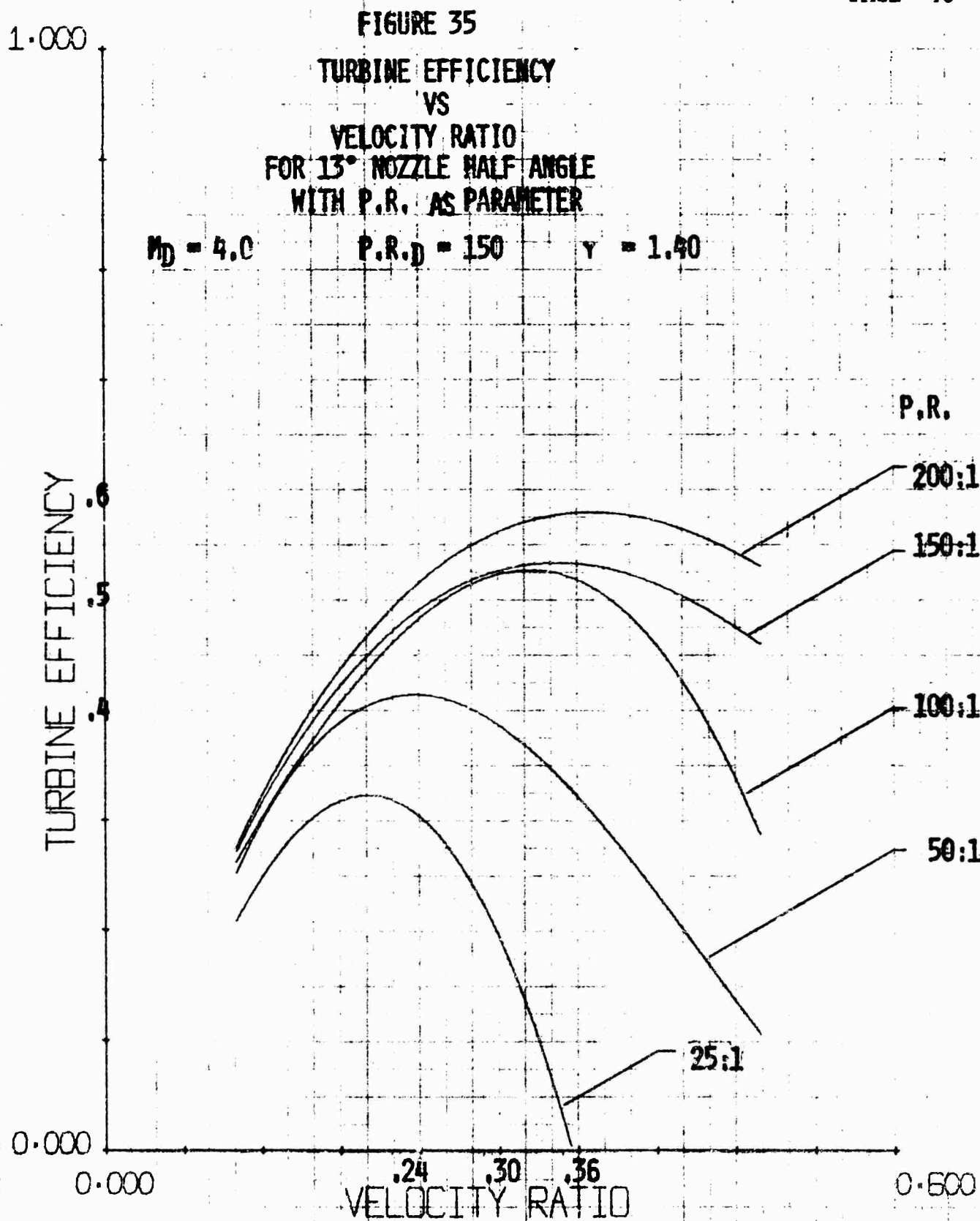


SUMMARY PLOT, MACH 2.5, HALF ANGLE = 7

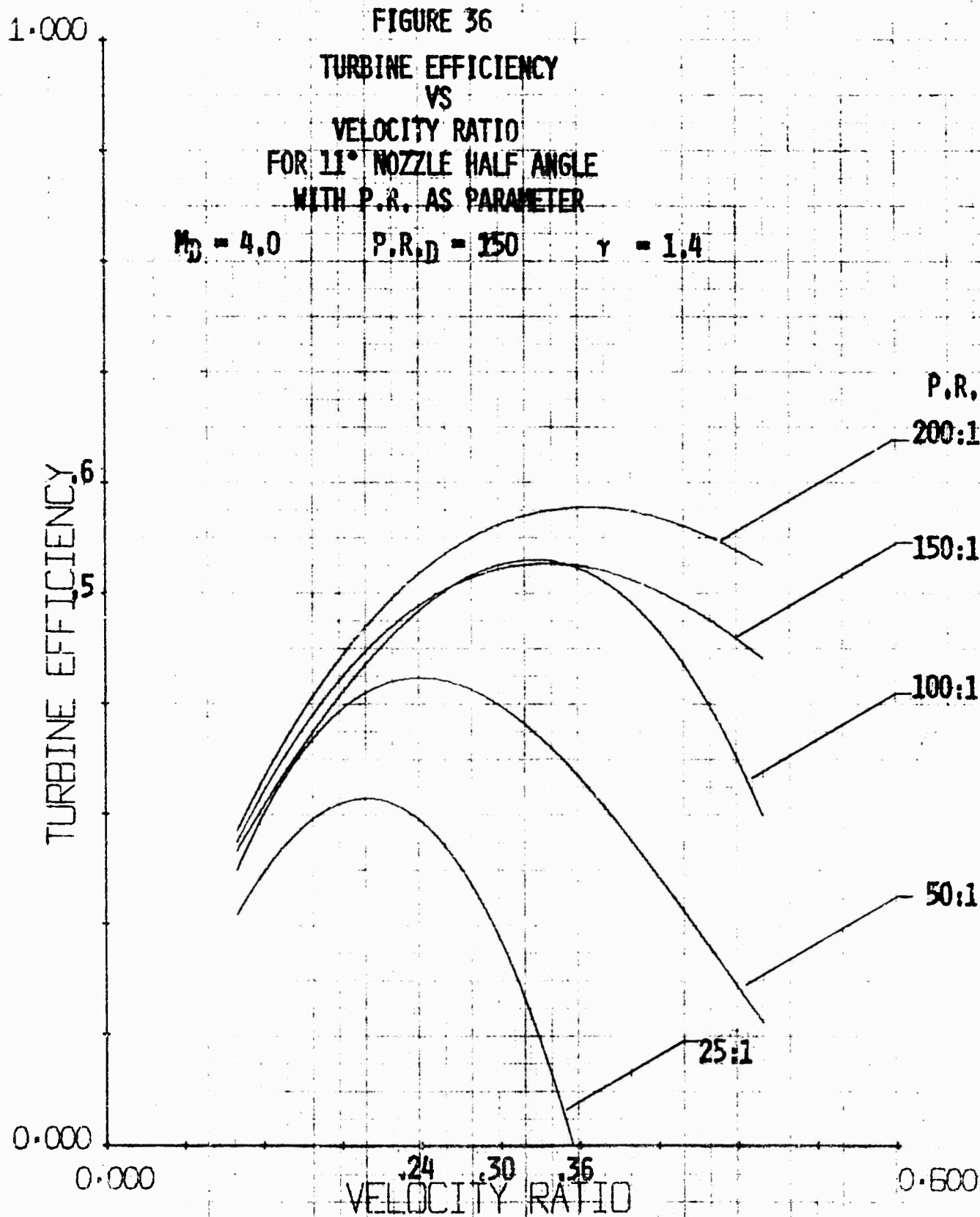


SUMMARY PLOT, MACH 4.0, HALF ANGLE=15°

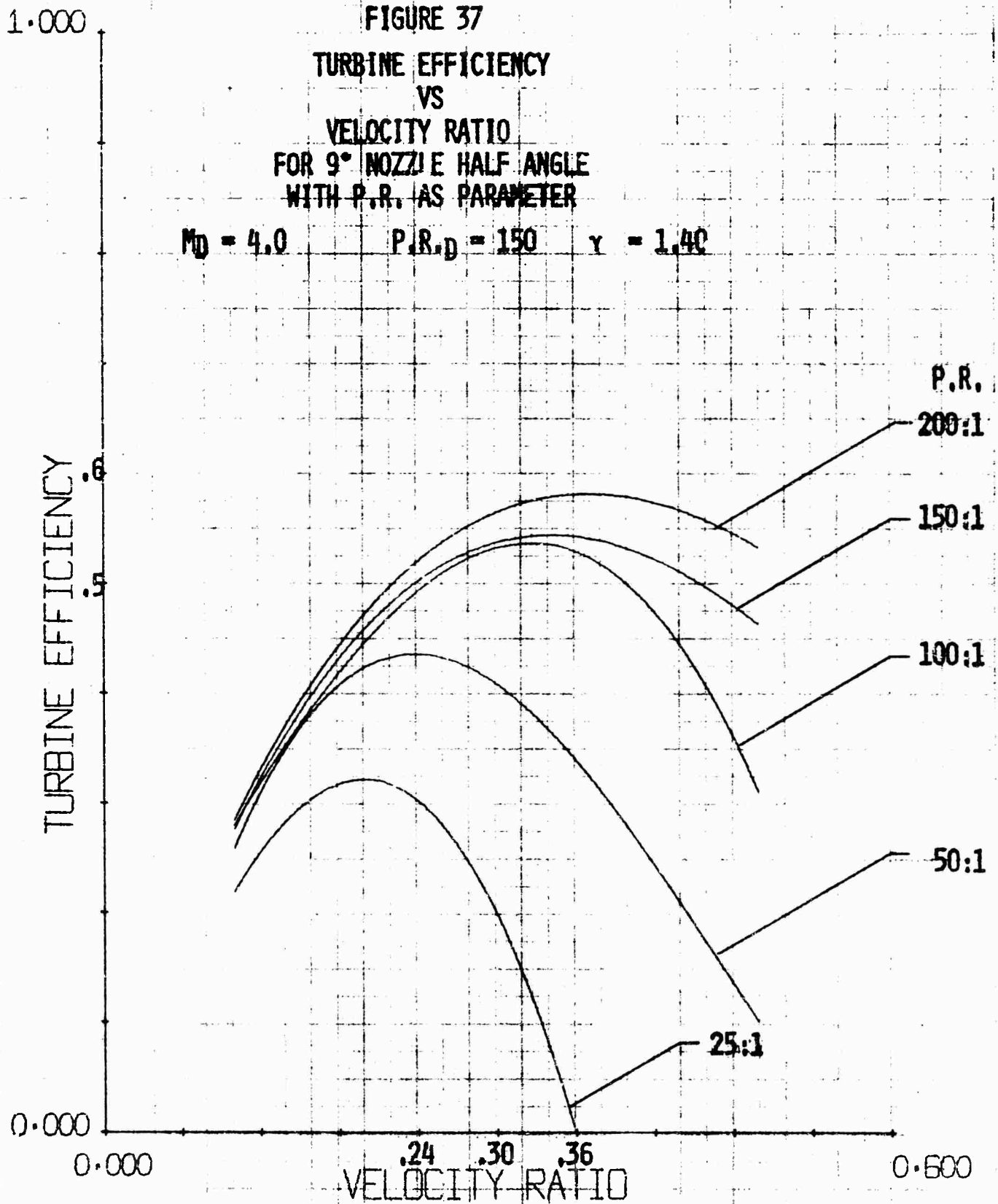




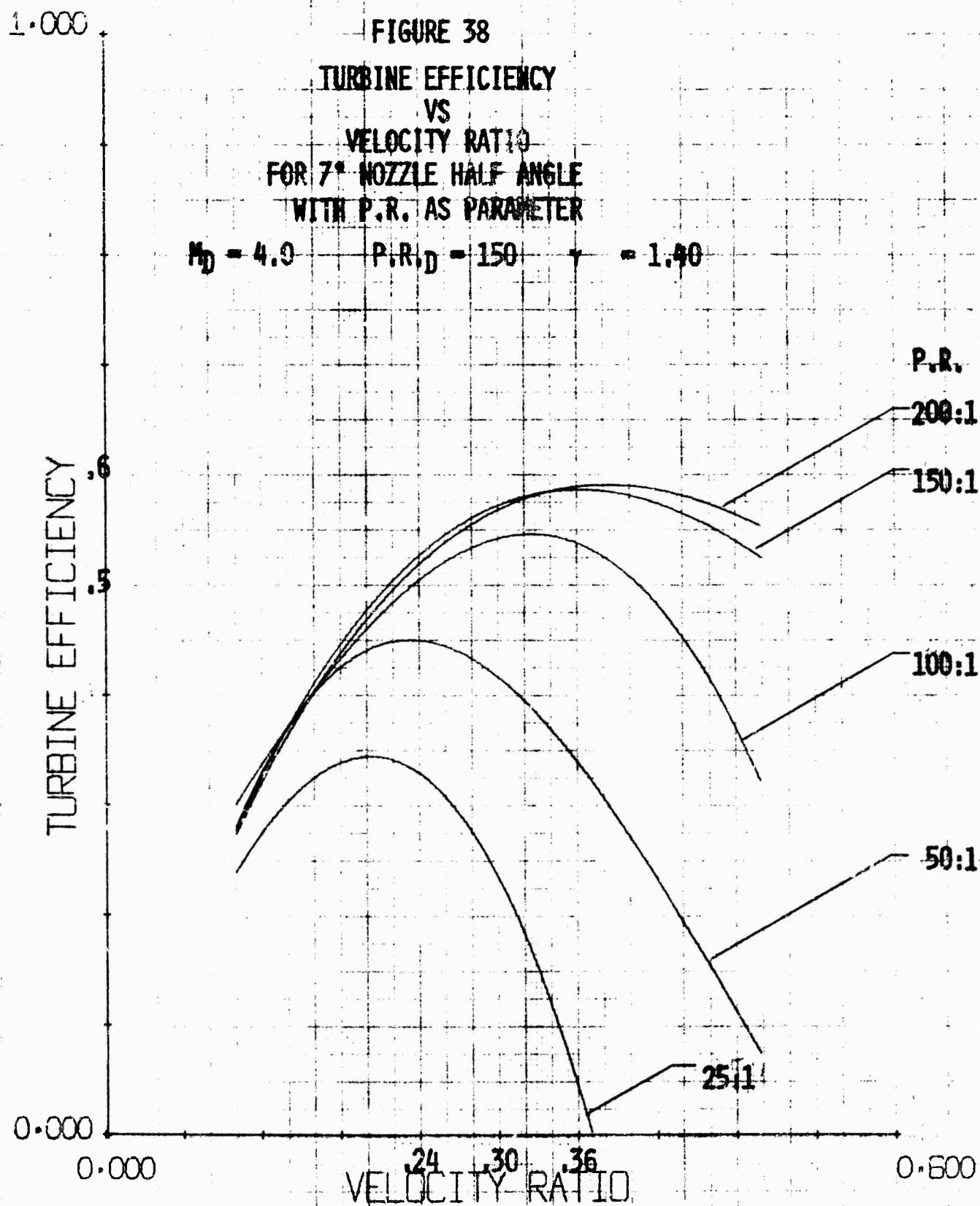
SUMMARY PLOT, MACH 4.0, HALF ANGLE=13°



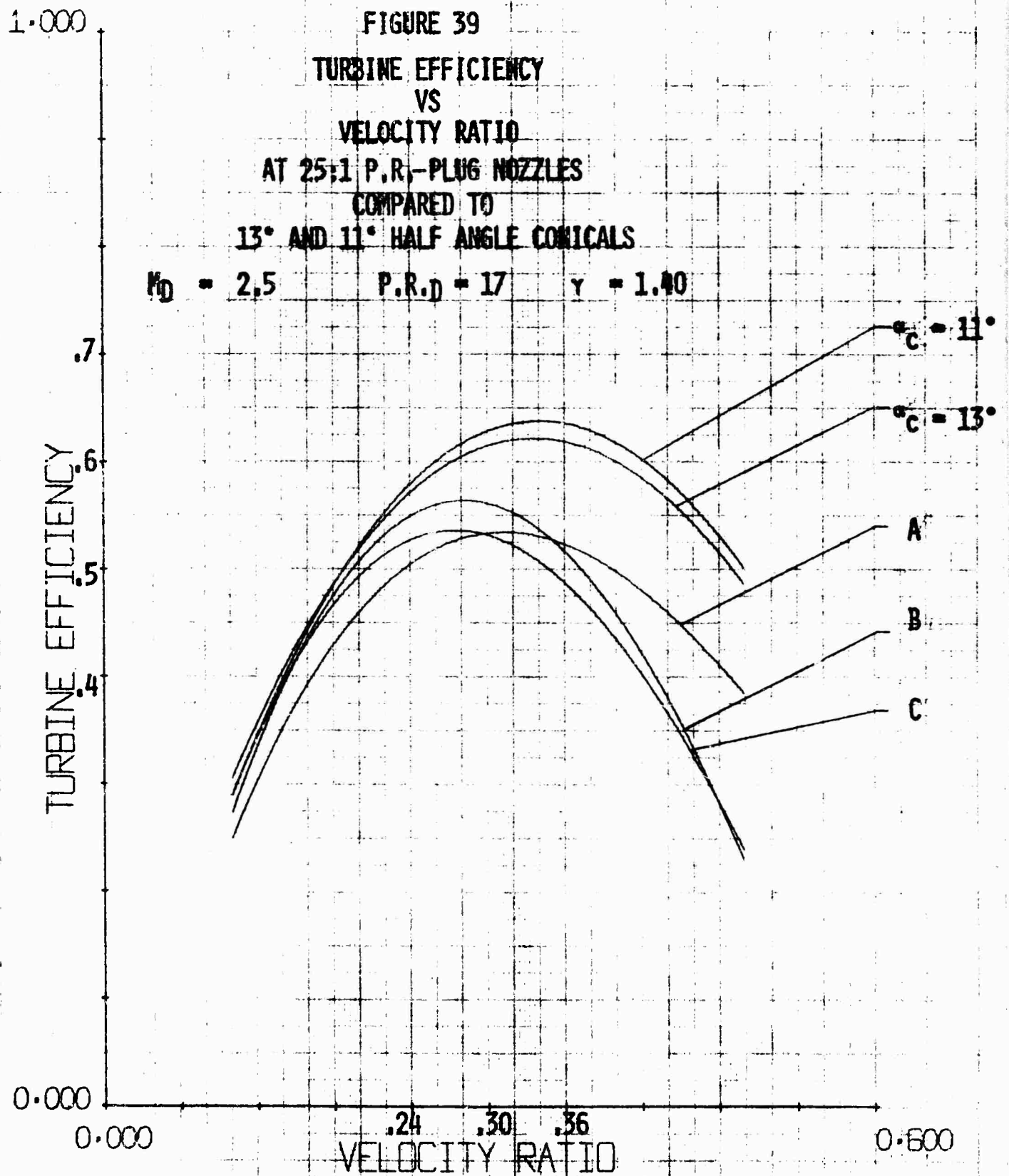
SUMMARY PLOT, MACH 4.0, HALF ANGLE=11°



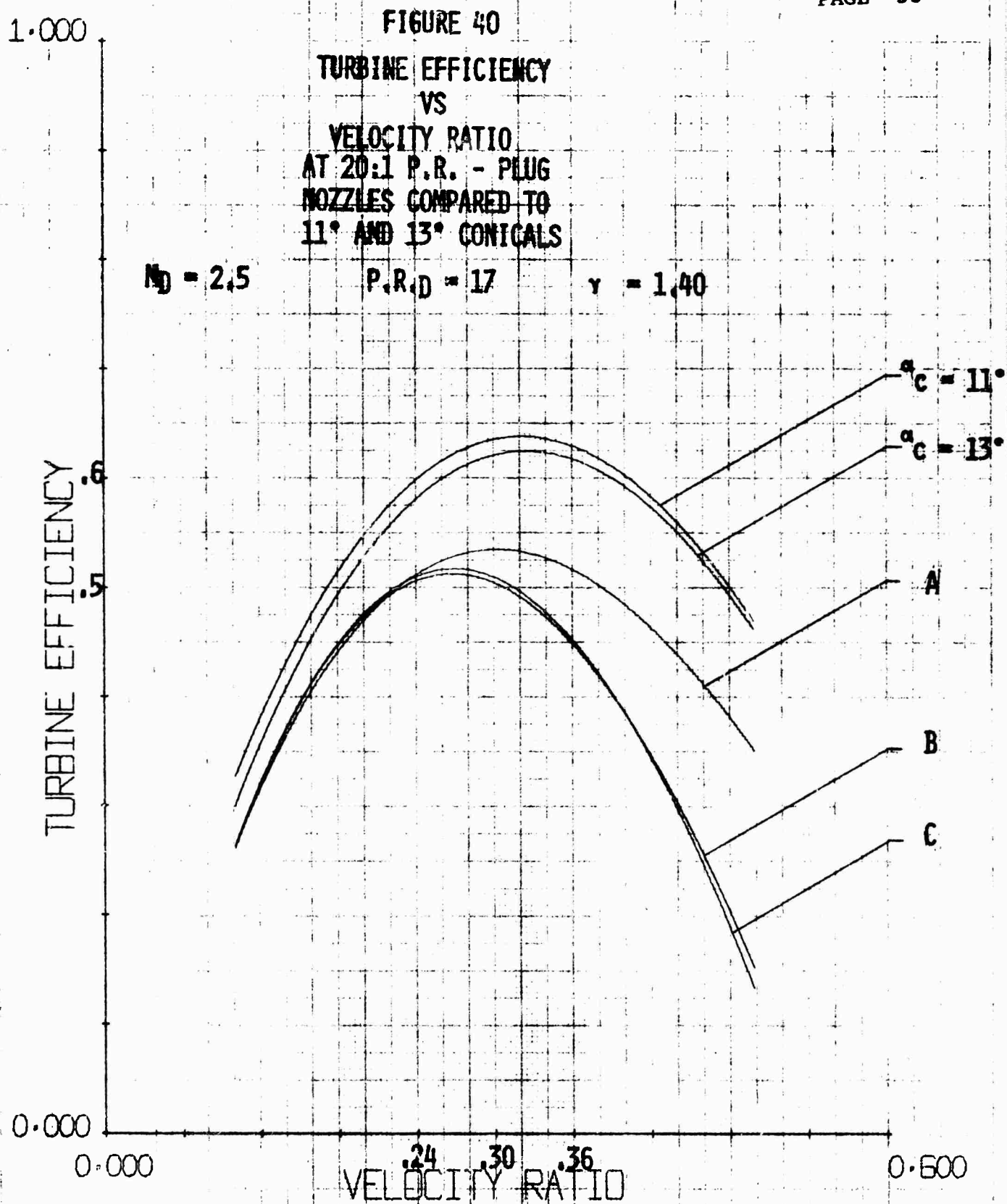
SUMMARY PLOT, MACH 4.0, HALF ANGLE=9°



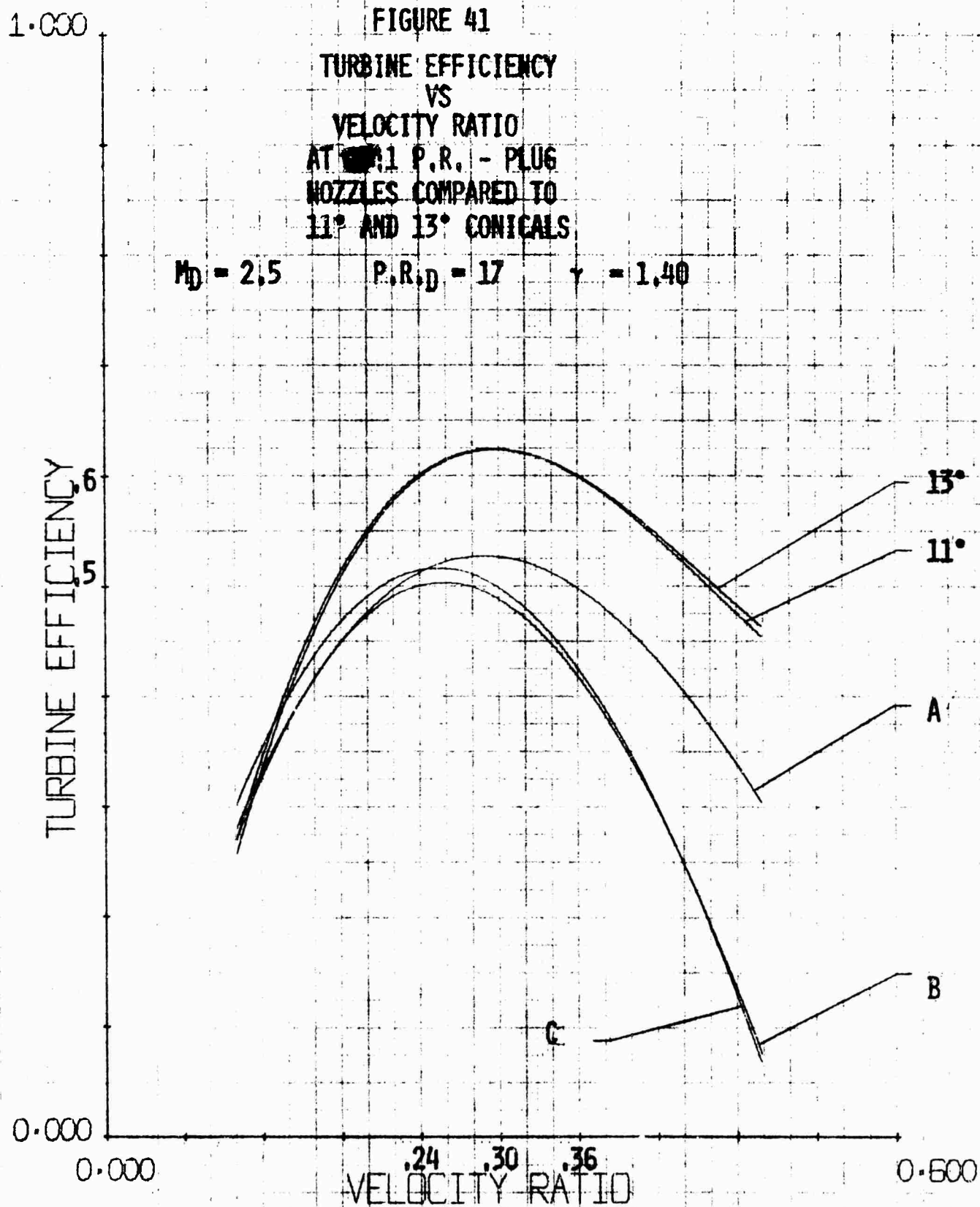
SUMMARY PLOT, MACH 4.0, HALF ANGLE=7



PLUG NOZZLE COMPARISON, PR. RATIO = 25

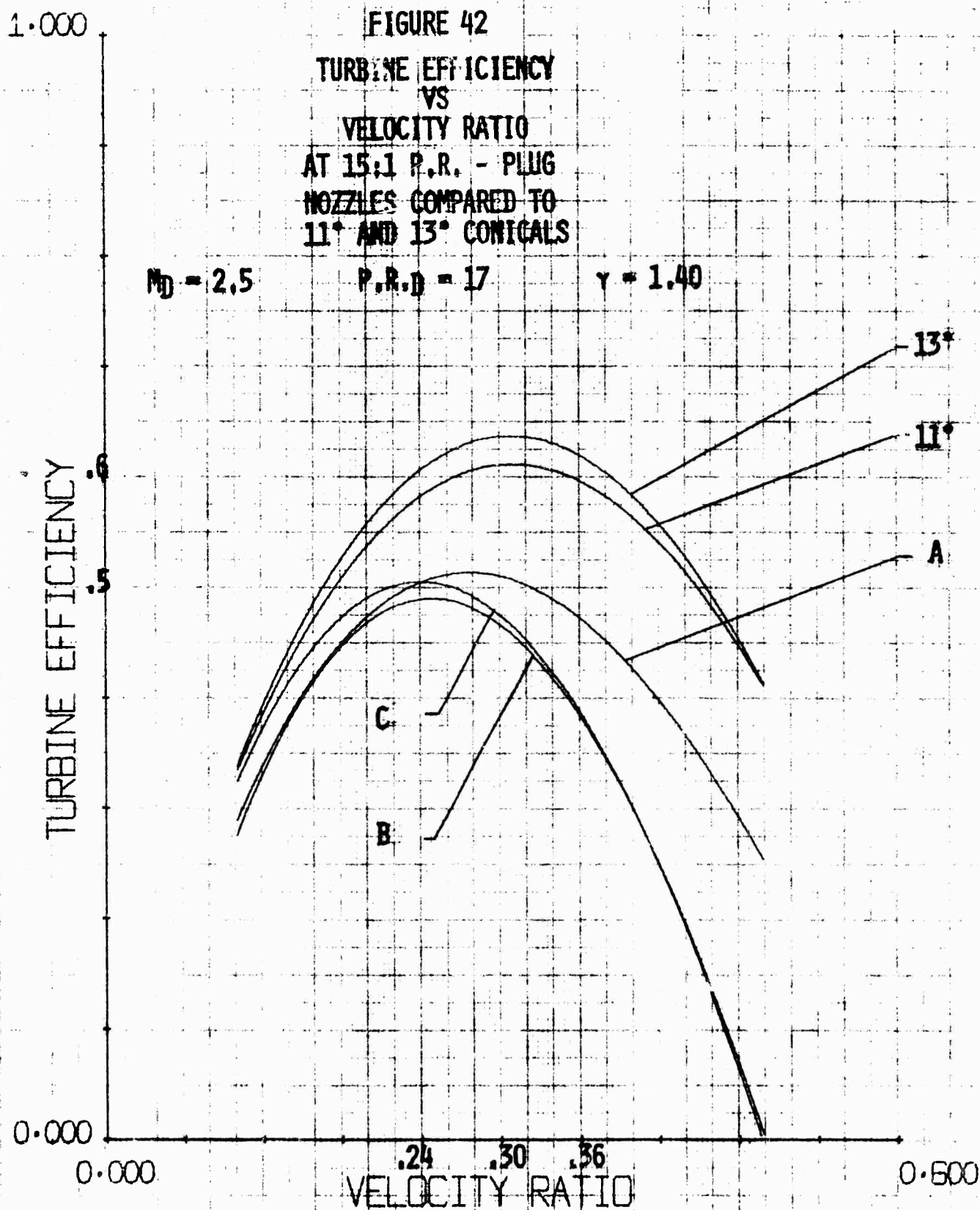


PLUG NOZZLE COMPARISON, PR. RATIO = 20



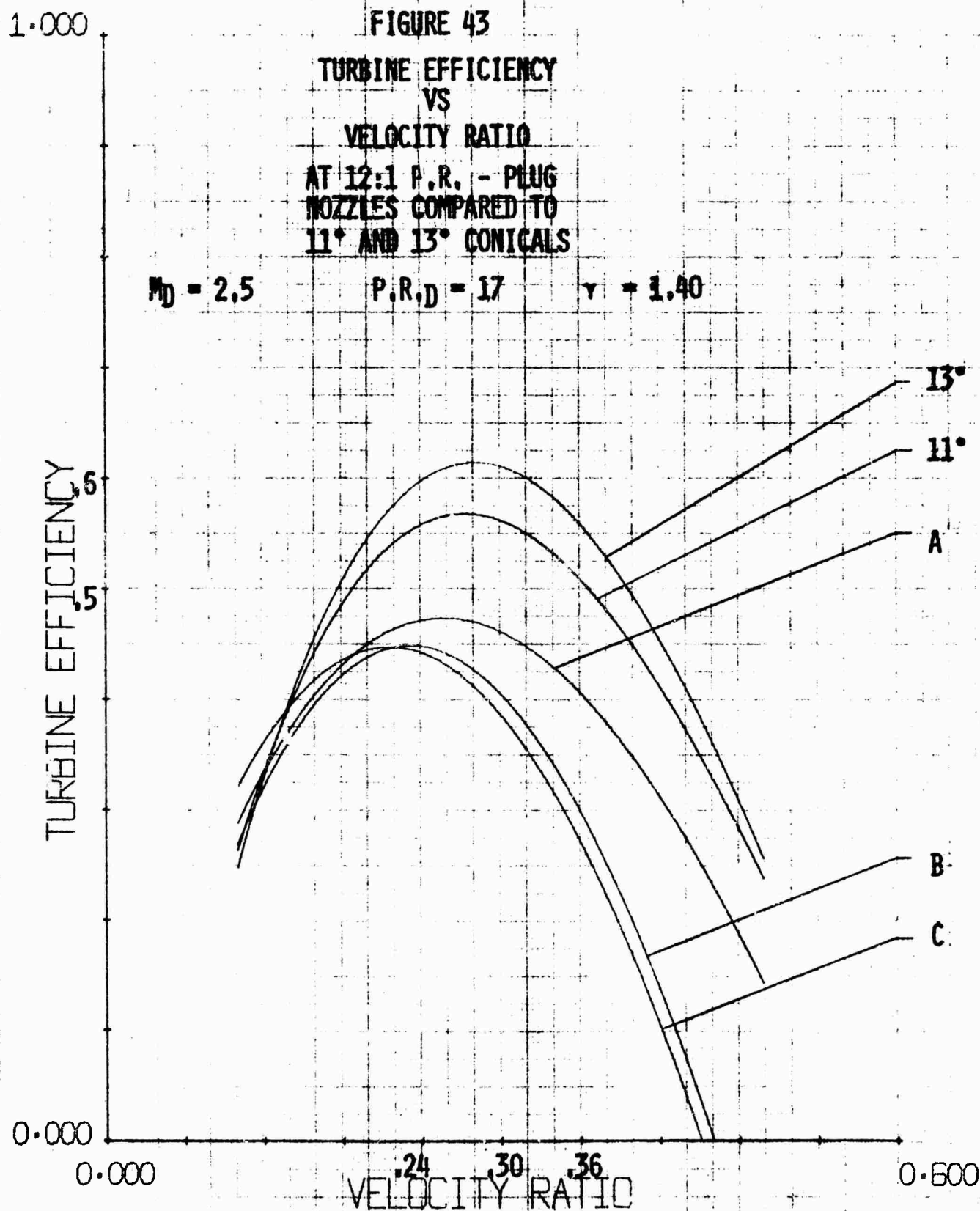
PLUG NOZZLE COMPARISON, P.R. RATIO = 17



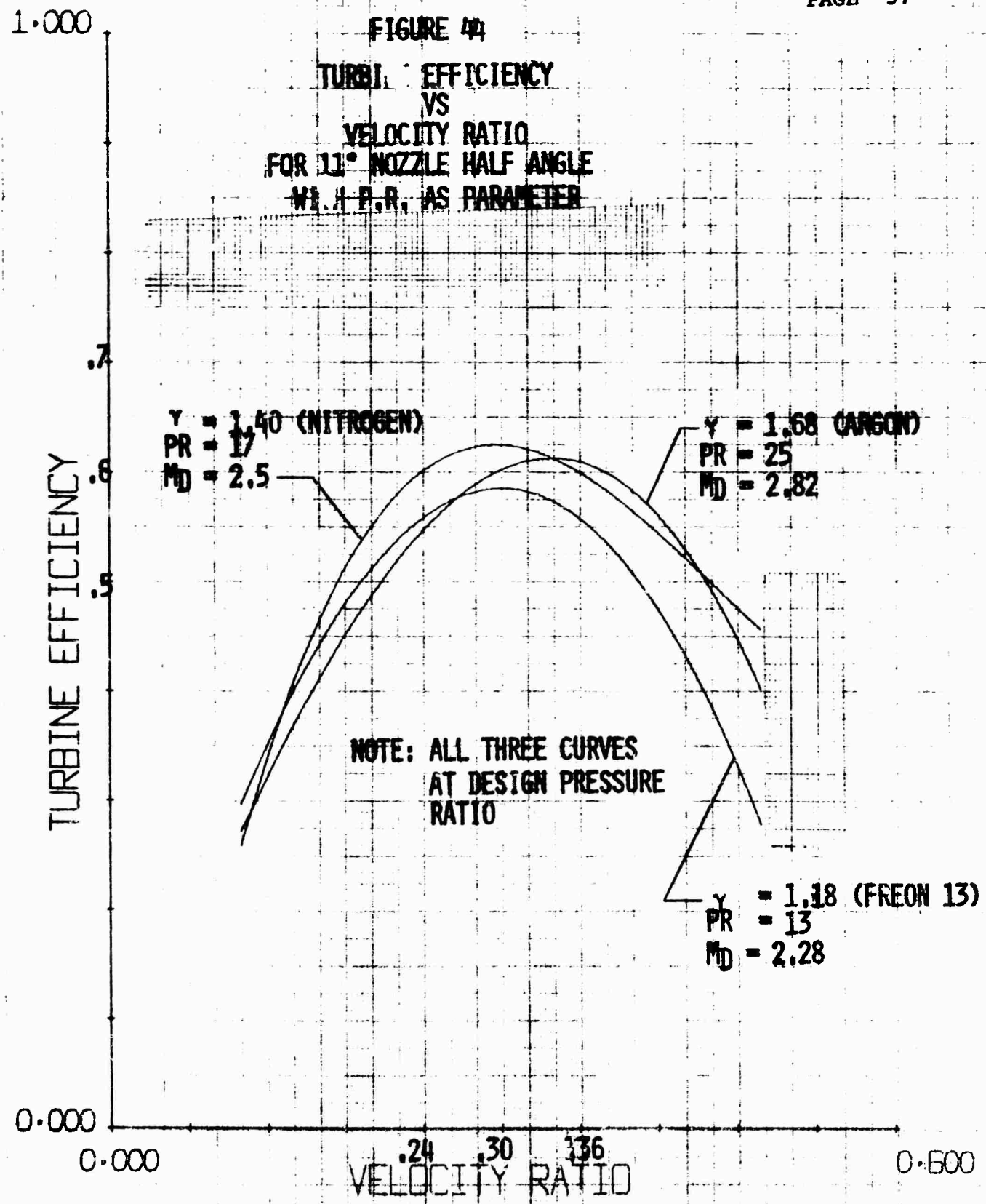


PLUG NOZZLE COMPARISON, PR. RATIO = 15

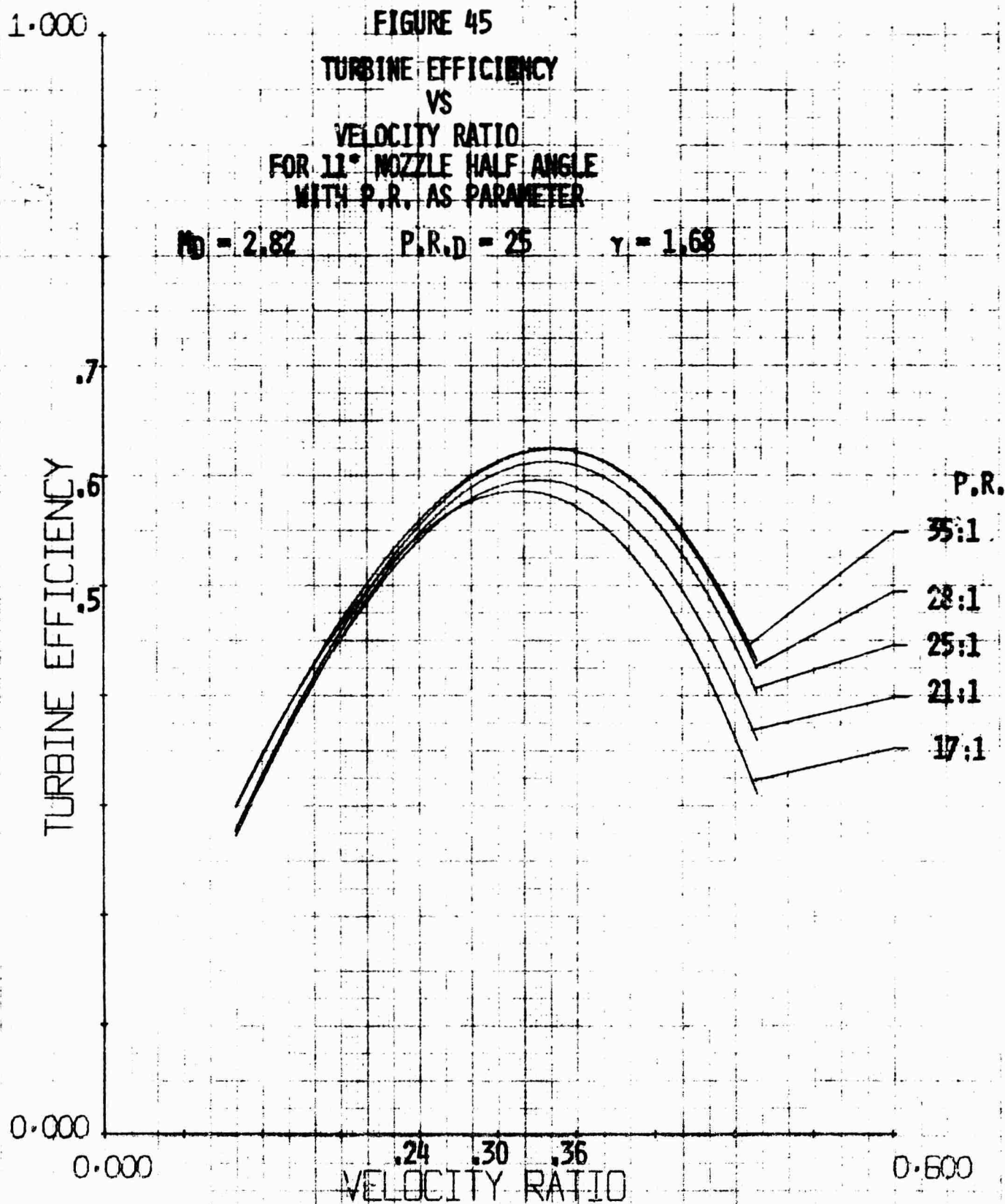




PLUG NOZZLE COMPARISON, PR. RATIO = 12



SUMMARY PLOT, ARGON, FREON, NITROGEN



SUMMARY PLOT, ARGON, HALF ANGLE=11

TABLE IV  
NOMINAL TEST CONDITIONS

Nozzle/Test (See Table II)	Nozzle Inlet Pressure psia	Exhaust Pressure psia	P.R.	Inlet Temp. °F
2.57	60	2.4	25	20-70
2.59	60	3.0	20	
2.511	60	3.5	17 des.	
2.513	60	4.0	15	
2.515	60	5.0	12	
Plug A	60	All Press. Each Nozzle		
Plug B	60			
Plug C	60			
4.7	240	1.2	200	20-70
		1.6	150 des.	
4.11	240	2.4	100	
		4.8	50	
4.15	240	9.6	25	
	98	2.8	35	0-60
	98	3.5	28	
Argon 2.511	98	3.9	25 des.	
	98	4.6	21	
	98	5.8	17	
Freon 2.511	91	7.1	12.8 des.	38-50

**3.0**

**CONCLUSIONS**

- 1) Turbines with low mach number supersonic nozzles should use nozzle half angles of about  $12^\circ$  to optimize performance.
- 2) Performance with high design mach number nozzles appears essentially independent of nozzle divergence.
- 3) Plug and contoured nozzles should be used with caution in turbines. Testing of three types showed no performance advantages.
- 4) Off-design performance improves with increased specific heat ratio.
- 5) Peak efficiency appears to exhibit a maximum as a function of specific heat ratio (at  $\gamma = 1.4$ ) although this effect is small.

**4.0**

**RECOMMENDATIONS**

Since this effort was primarily an experimental study the discussion and conclusions are on the order of obvious observations. The large quantity of data were organized in only an elementary way and a thorough theoretical analysis and interpretation of it would be a significant contribution to the advancement of turbine performance and design.

5.0

SYMBOLS

A	nozzle area	in. <sup>2</sup>
C <sub>D</sub>	nozzle discharge coefficient	<u>W-measured</u> <u>W-theoretical</u>
C <sub>O</sub>	isentropic spouting velocity	ft/sec
D <sub>e</sub>	diameter of nozzle exit	in.
D*	diameter of nozzle throat	in.
M	mach number	
P	static pressure	psia
P <sub>T</sub>	total pressure	psia
P <sub>R</sub>	total to static pressure ratio	
U	turbine tip speed	ft/sec
W	nozzle weight flow	lb/sec
α <sub>C</sub>	nozzle cone half angle	degrees
γ	gas ratio of specific heats	
η <sub>t</sub>	turbine efficiency	

SUBSCRIPTS

O	nozzle entrance
*	nozzle throat
e	nozzle exit plane
D	design

## 6.0

LIST OF REFERENCES

1. Barber, R. E. and Schultheiss, M. J.,  
"The Effect of Nozzle Geometry on Off-Design  
Performance of Partial Admission Impulse Turbines",  
Sundstrand Aviation AER 486, April 1967.
2. Rao, G. V. R., "Approximation of Optimum Thrust  
Nozzle Contours", Jet Propulsion Vol. 30, June 1960.
3. Carnahan, B., Luter, H. A. and Wilkes, J. O.,  
"Applied Numerical Analysis", John Wiley and Sons,  
1969.
4. "Tables of Thermal Properties of Gases",  
National Bureau of Standards, Circular 564, 1955.
5. El Dupont De Nemours & Co., "Freon 13 Thermodynamic  
Properties"; Pressure Enthalpy Diagram for Freon 13;  
"Transport Properties of Freon Fluorocarbons".

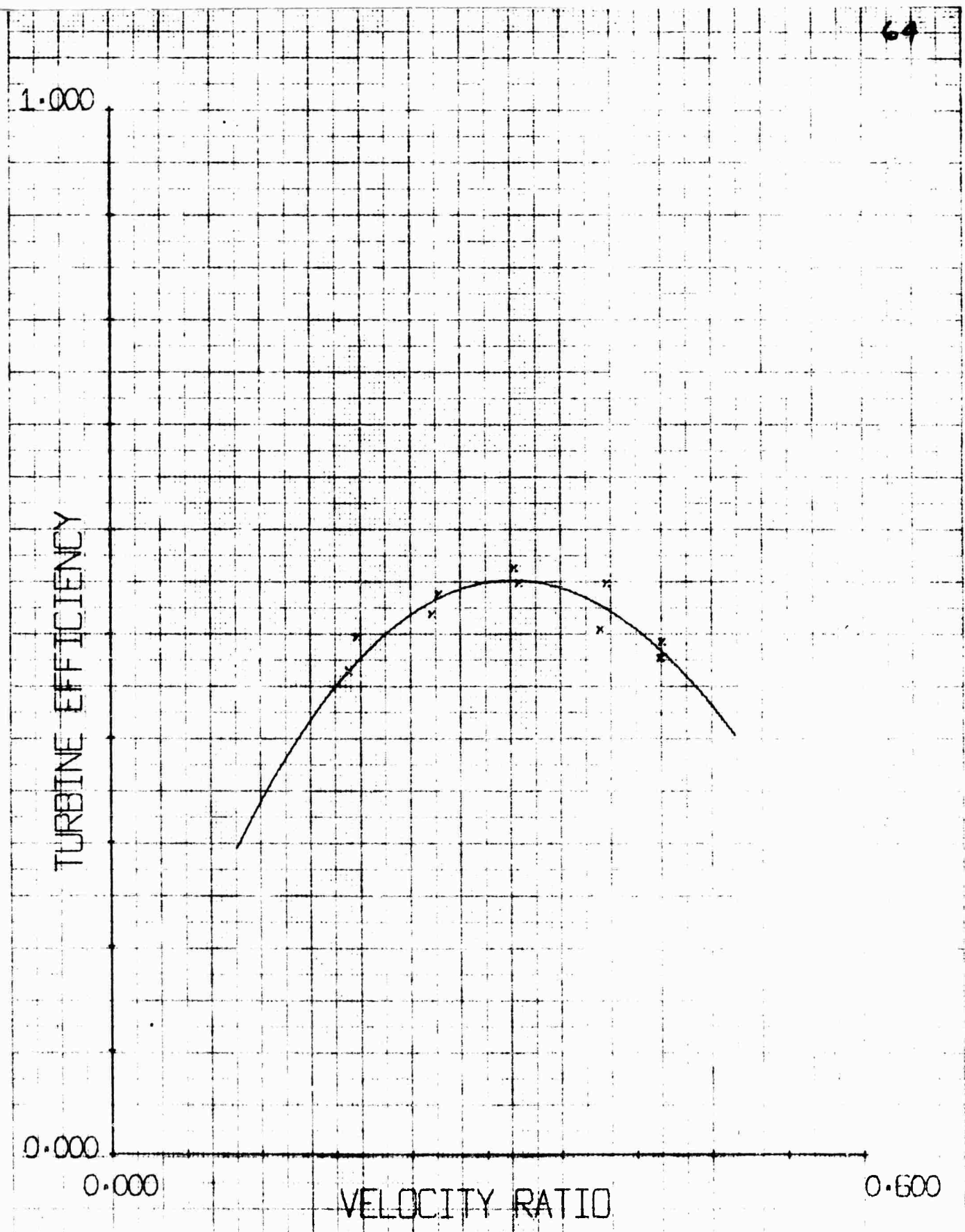
**SUNDSTRAND AVIATION**  
**Rockford, Illinois**

**ATR 2001**  
**PAGE 63**

**APPENDIX A**

**GRAPHS OF INDIVIDUAL TEST  
RESULTS WITH EMPIRICAL  
DATA POINTS**





MACH 2.5, PR. RATIO=25, HALF ANGLE=15

1.000

TURBINE EFFICIENCY

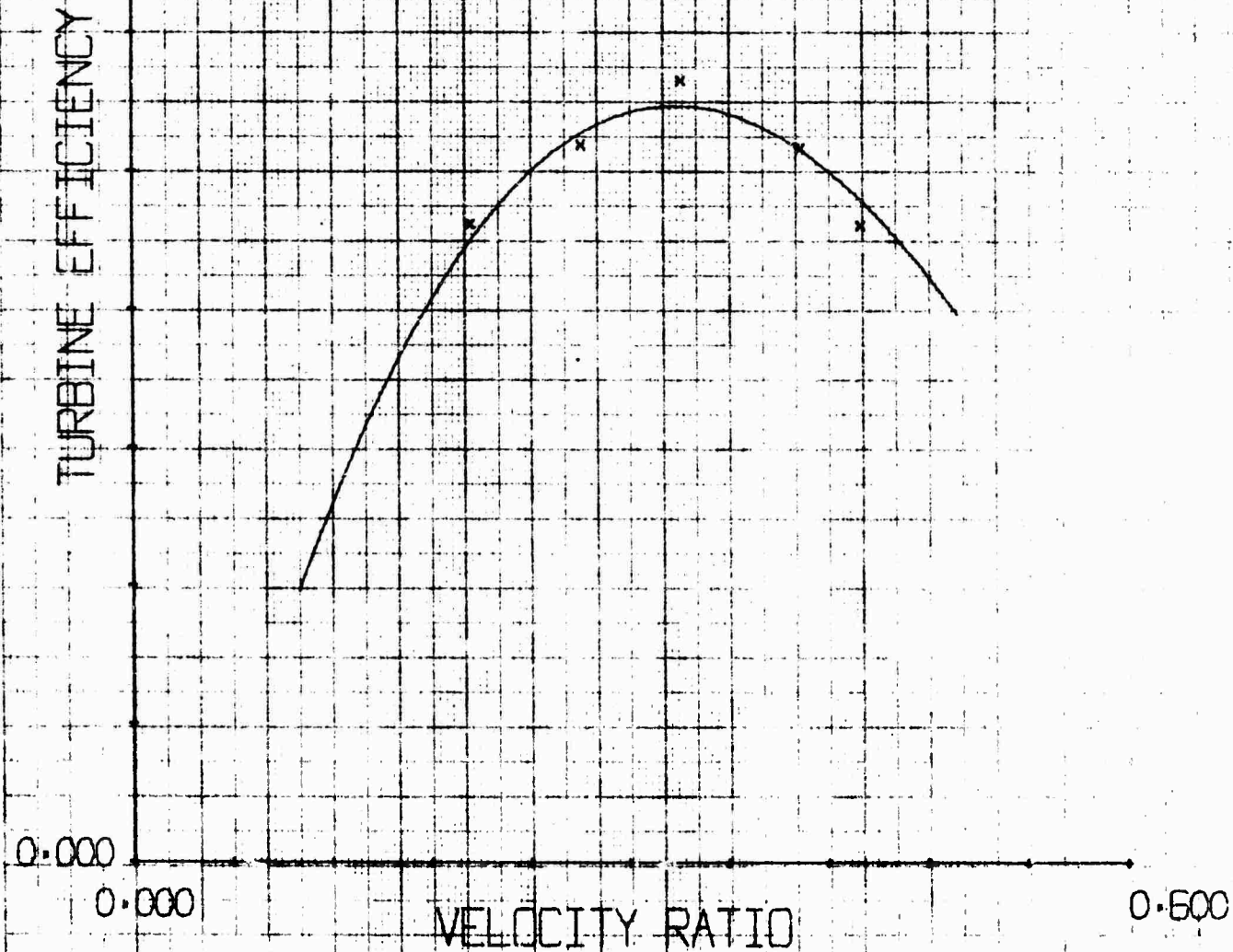
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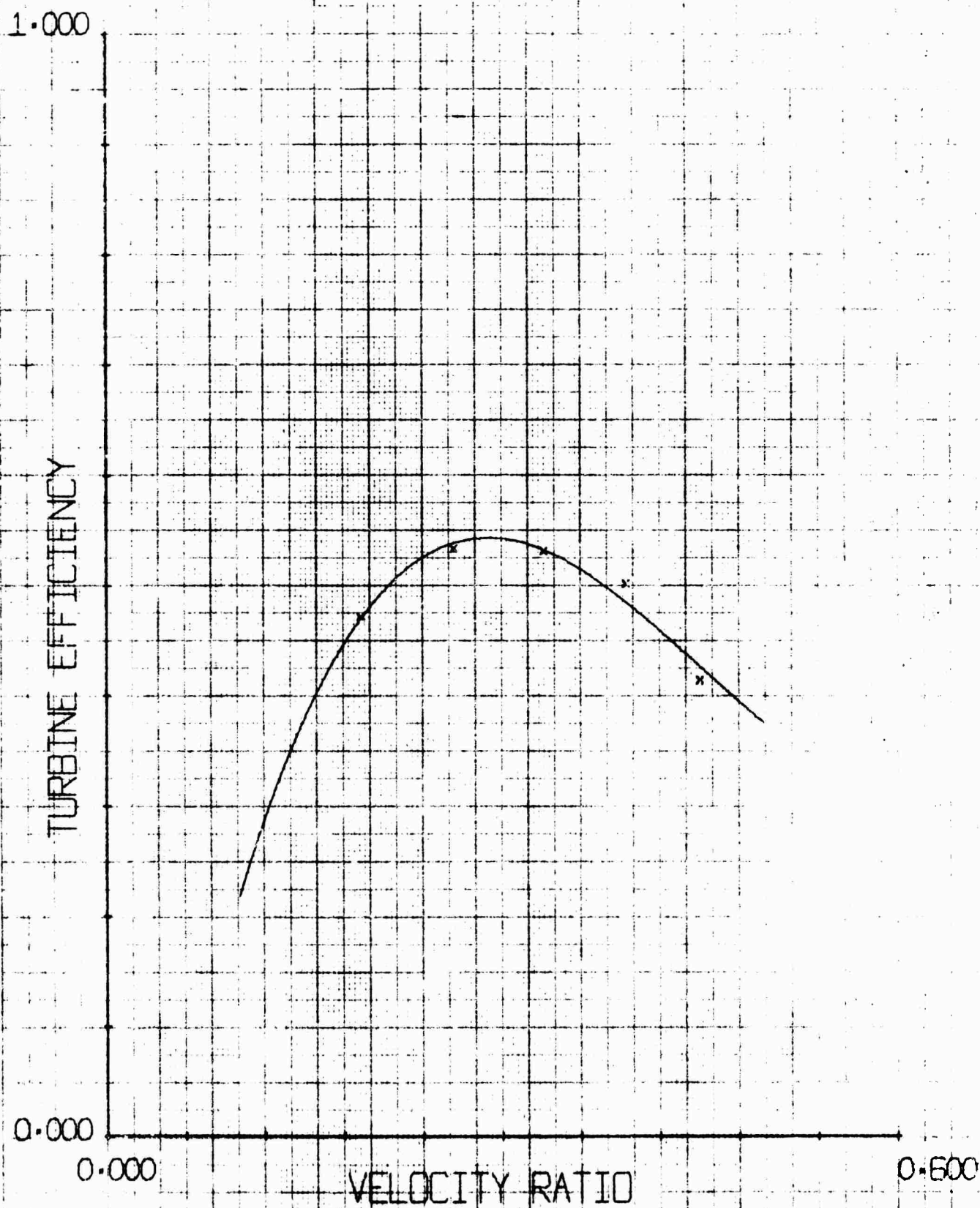
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VELOCITY RATIO

0.500

MACH 2.5, PR. RATIO=20, HALF ANGLE=15





MACH 2.5, PR. RATIO=17, HALF ANGLE=15

1.000

TURBINE EFFICIENCY

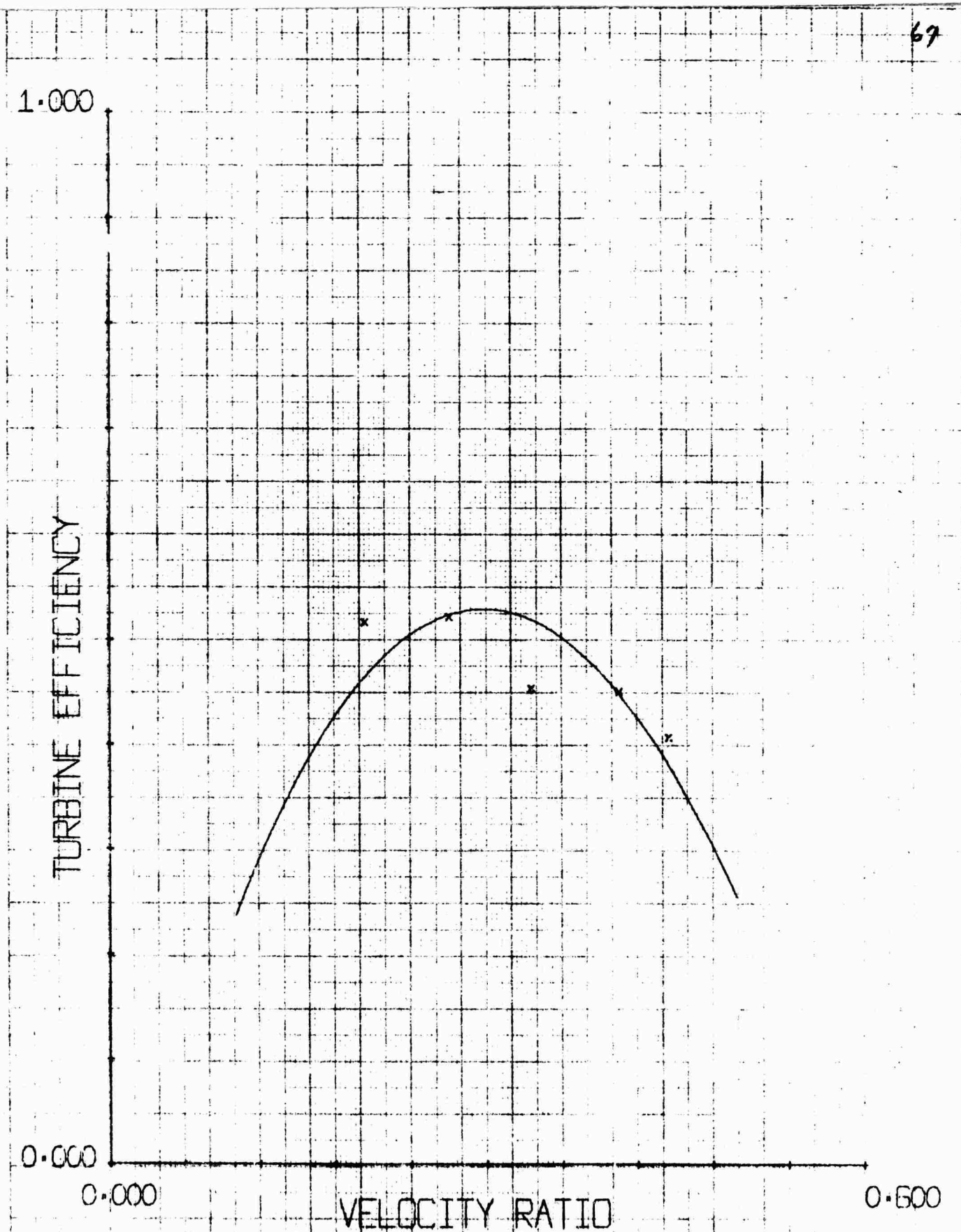
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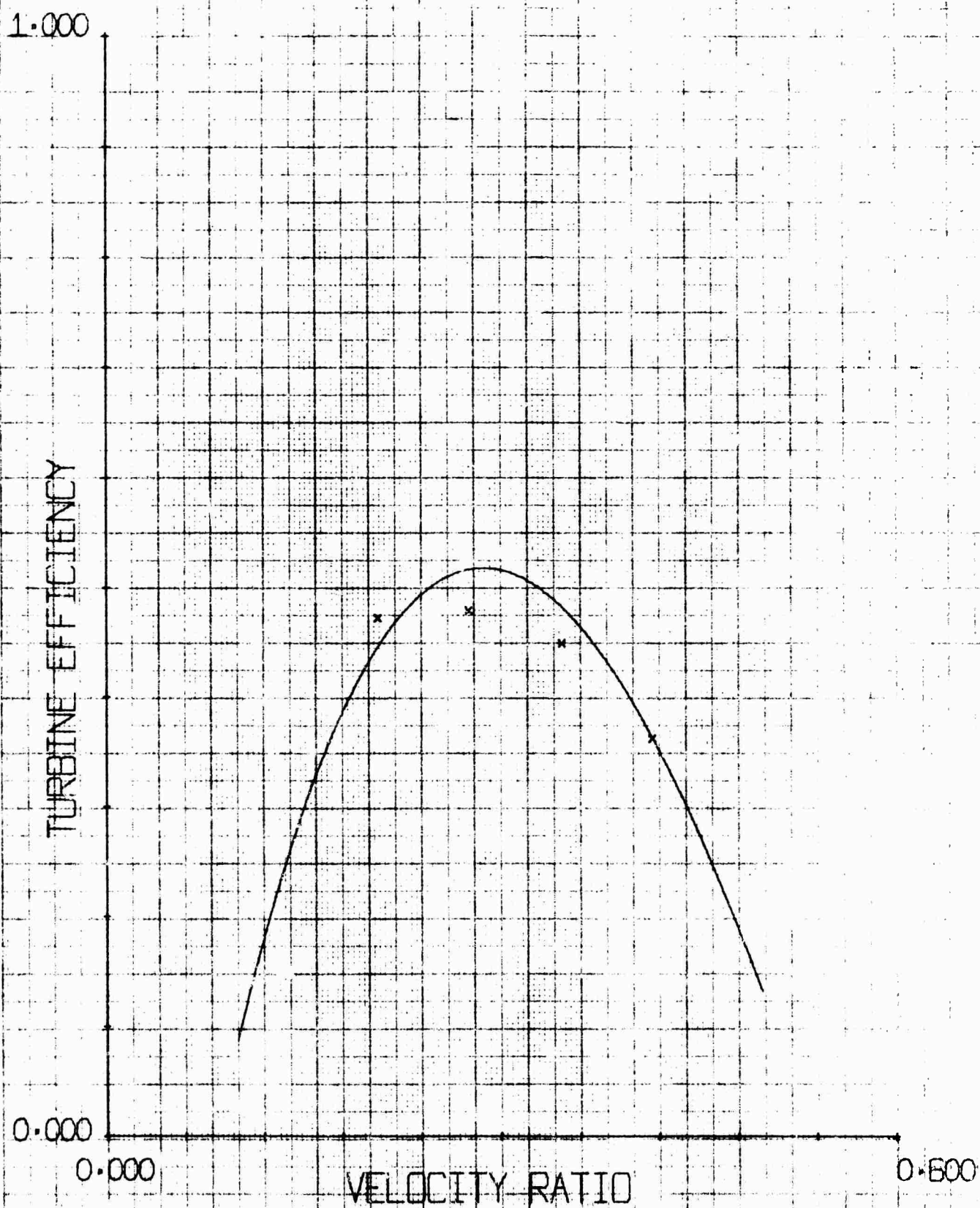
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VELOCITY RATIO

0.600

MACH 2.5, PR. RATIO=15, HALF ANGLE=15





MACH 2.5, PR. RATIO=12, HALF ANGLE=15



1.000

TURBINE EFFICIENCY

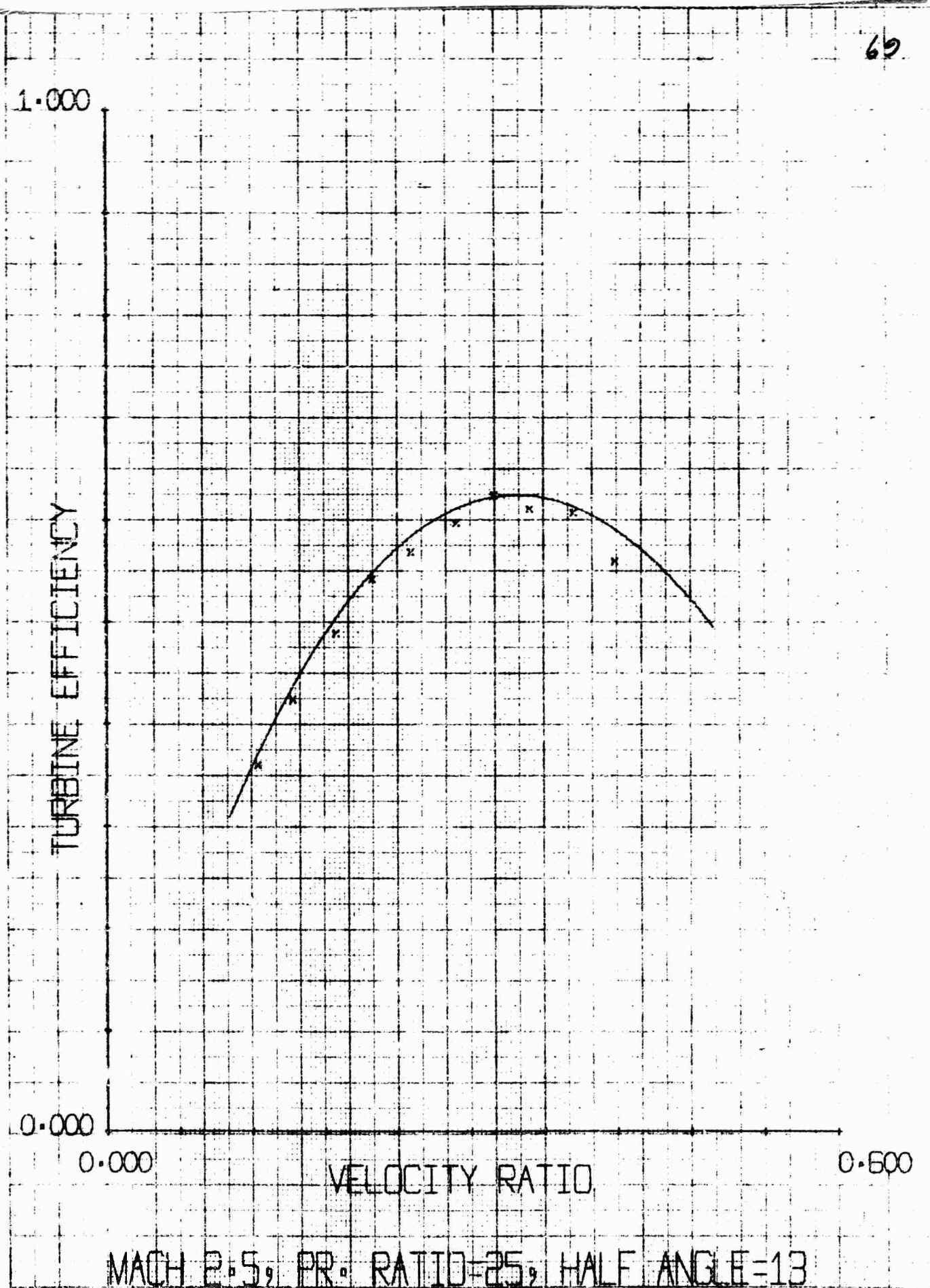
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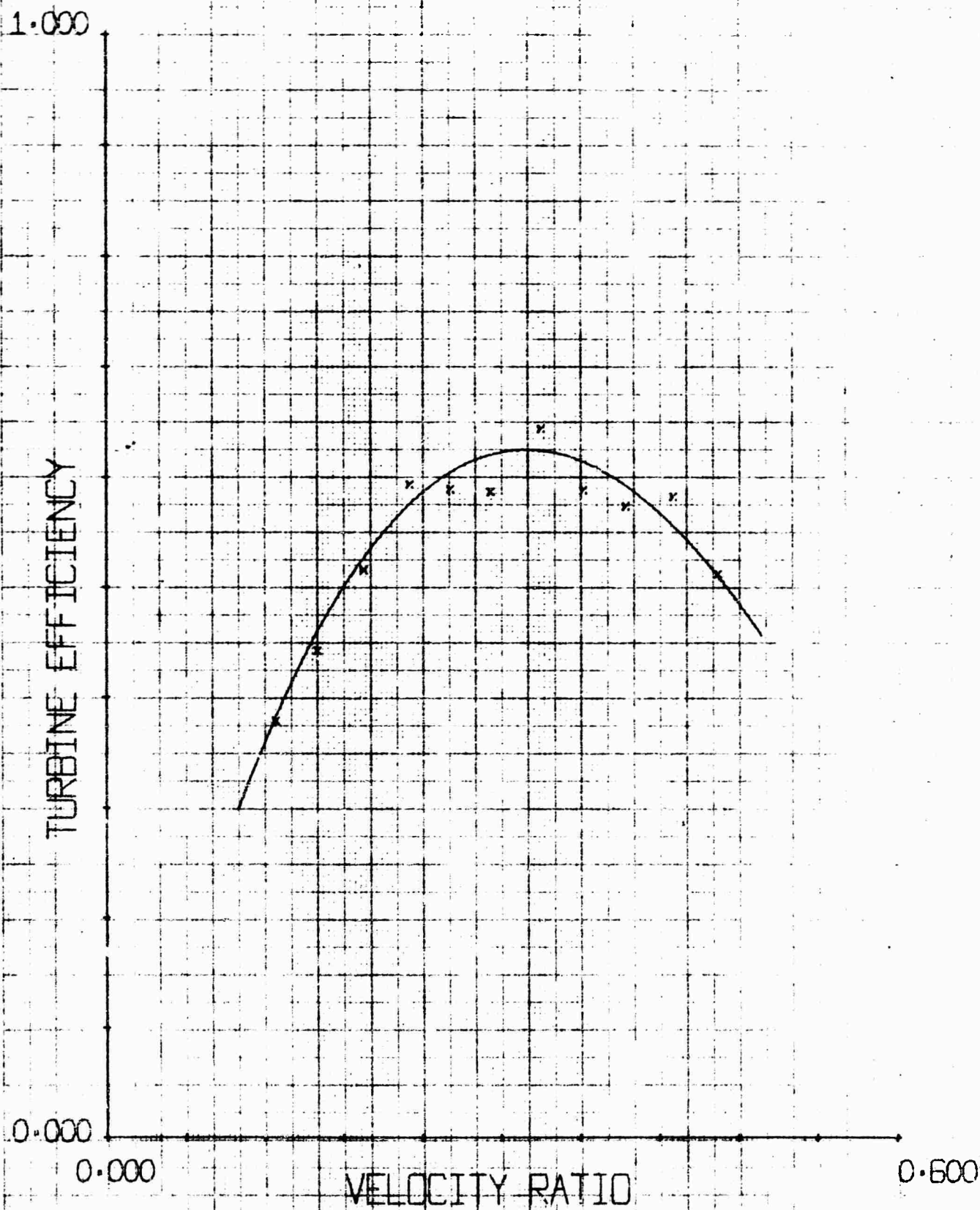
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VELOCITY RATIO

0.600

MACH 2.5; PR. RATIO=25; HALF ANGLE=13





MACH 2.5, PR. RATIO=20, HALF ANGLE=13

1.000

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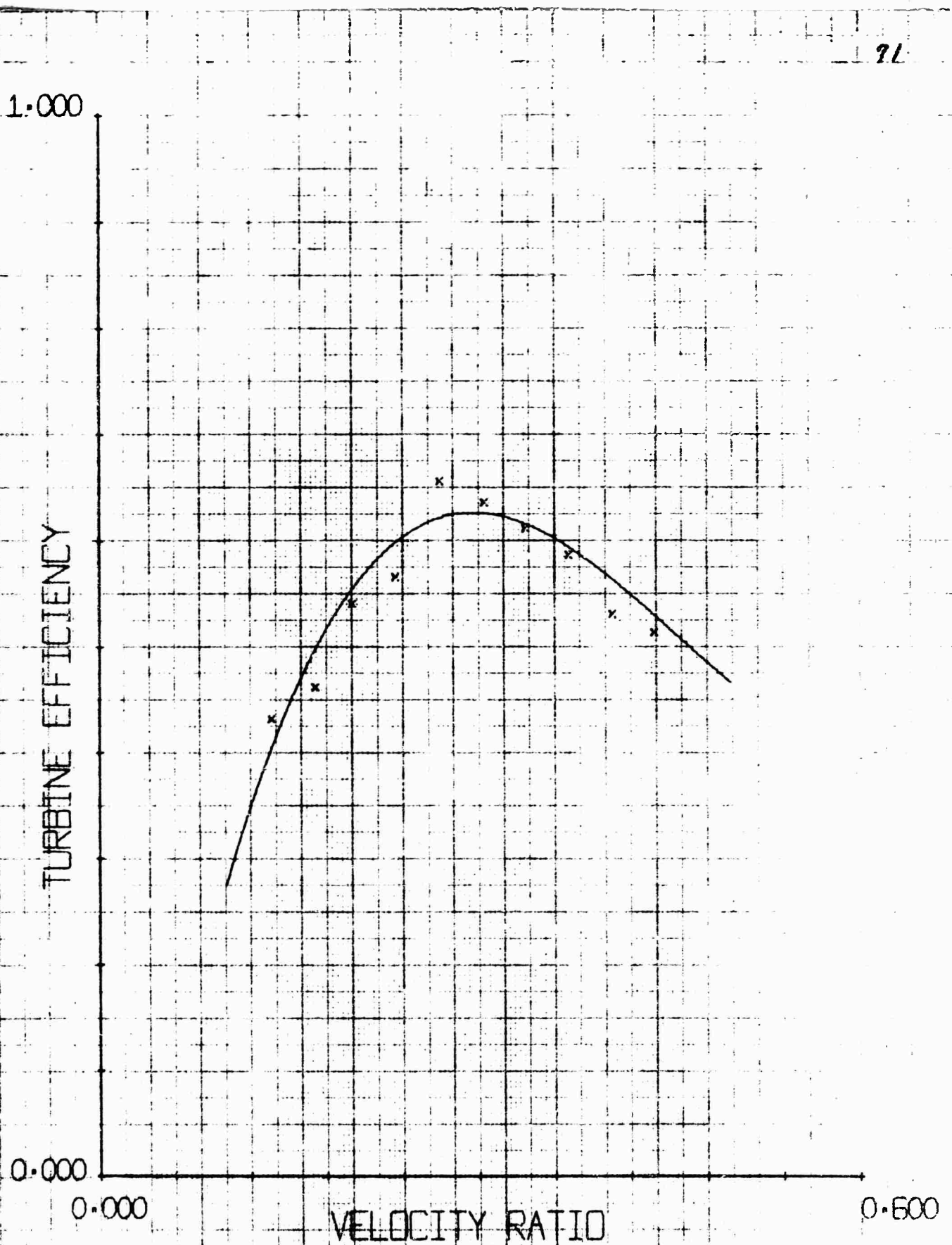
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=17, HALF ANGLE=13





1.000

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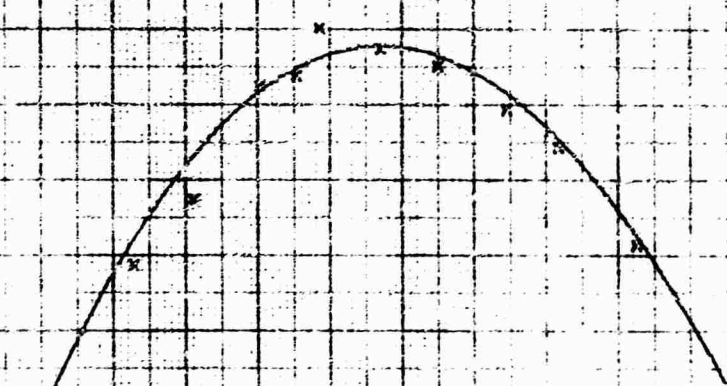
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=15, HALF ANGLE=13



1.000

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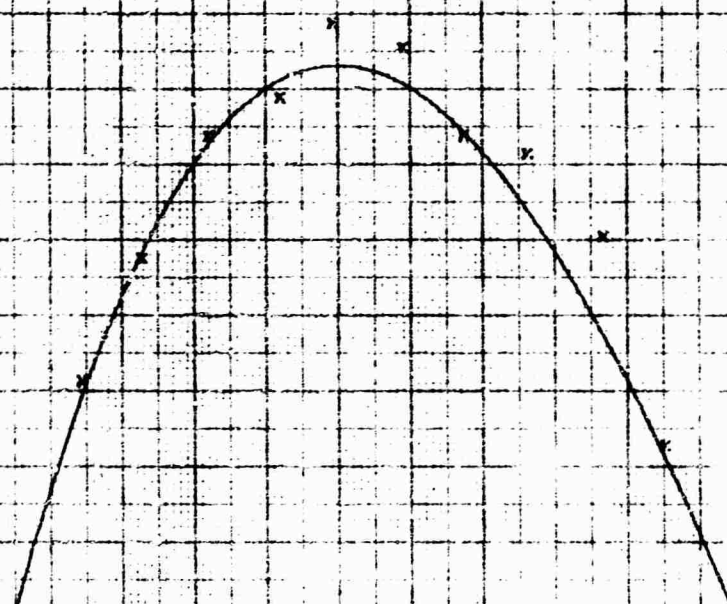
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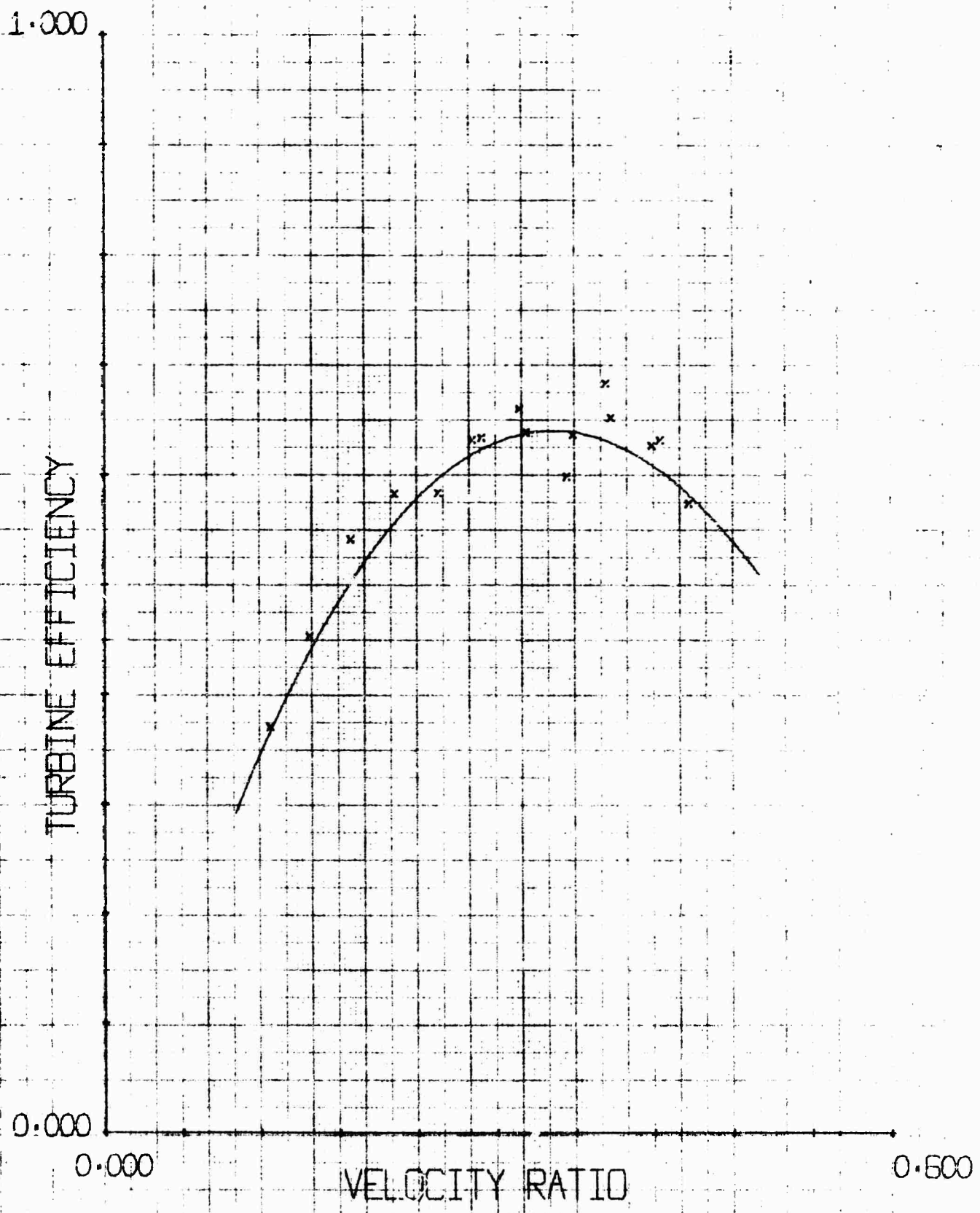
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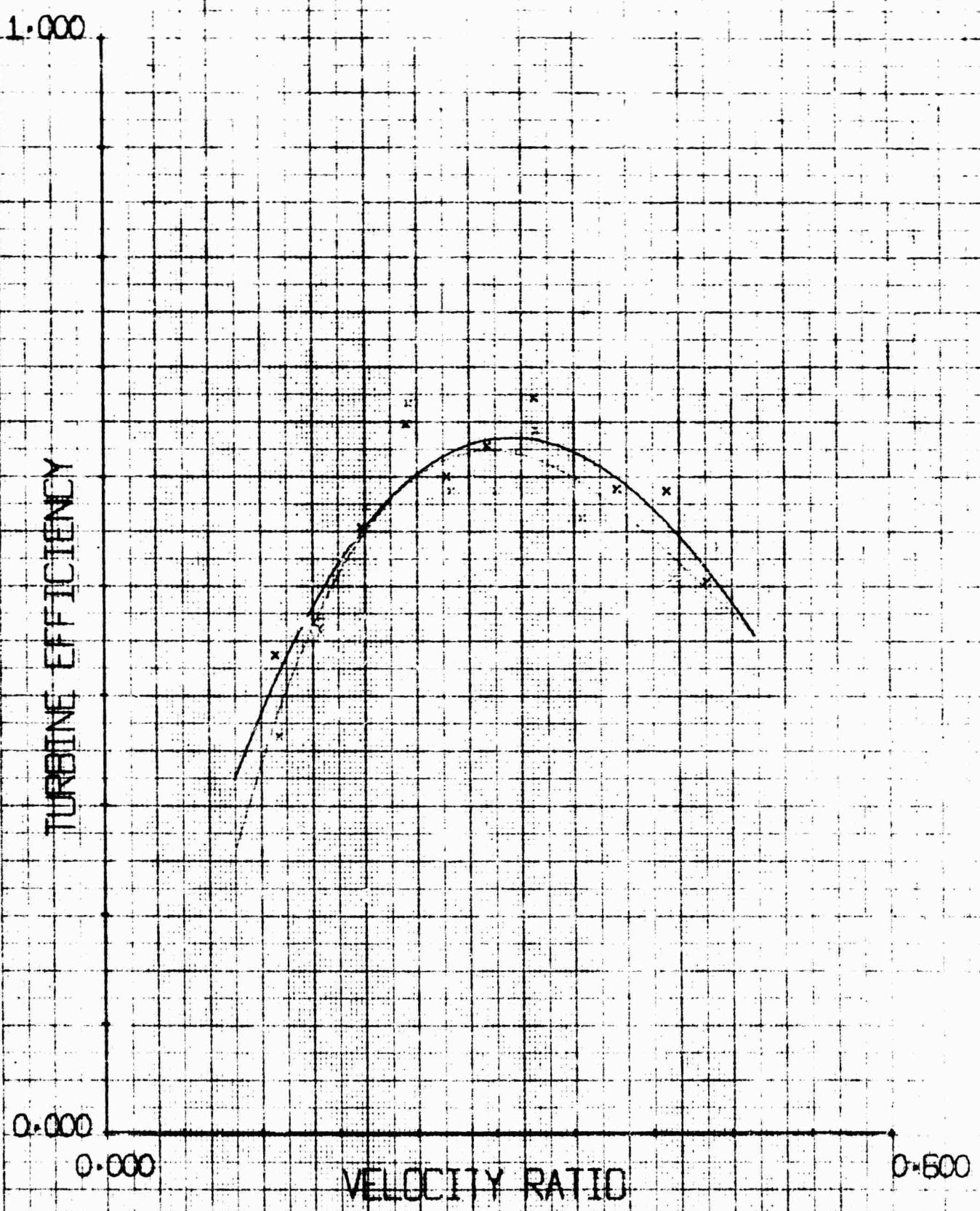
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MACH 2.5, PR. RATIO=12, HALF ANGLE=13





MACH 2.5, PR. RATIO=25, HALF ANGLE=11



MACH 2.5, PR. RATIO=20, HALF ANGLE=11



1.000

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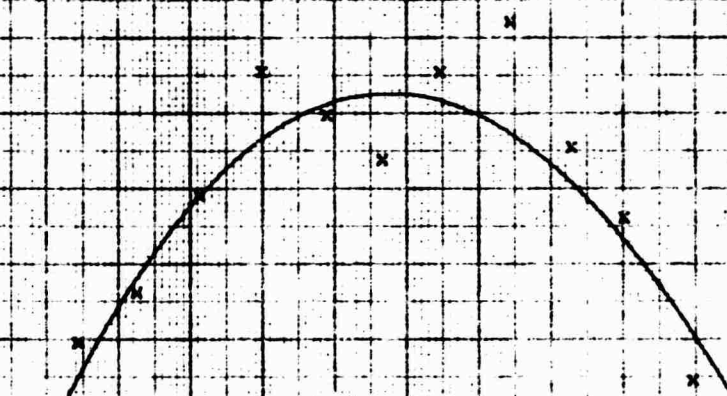
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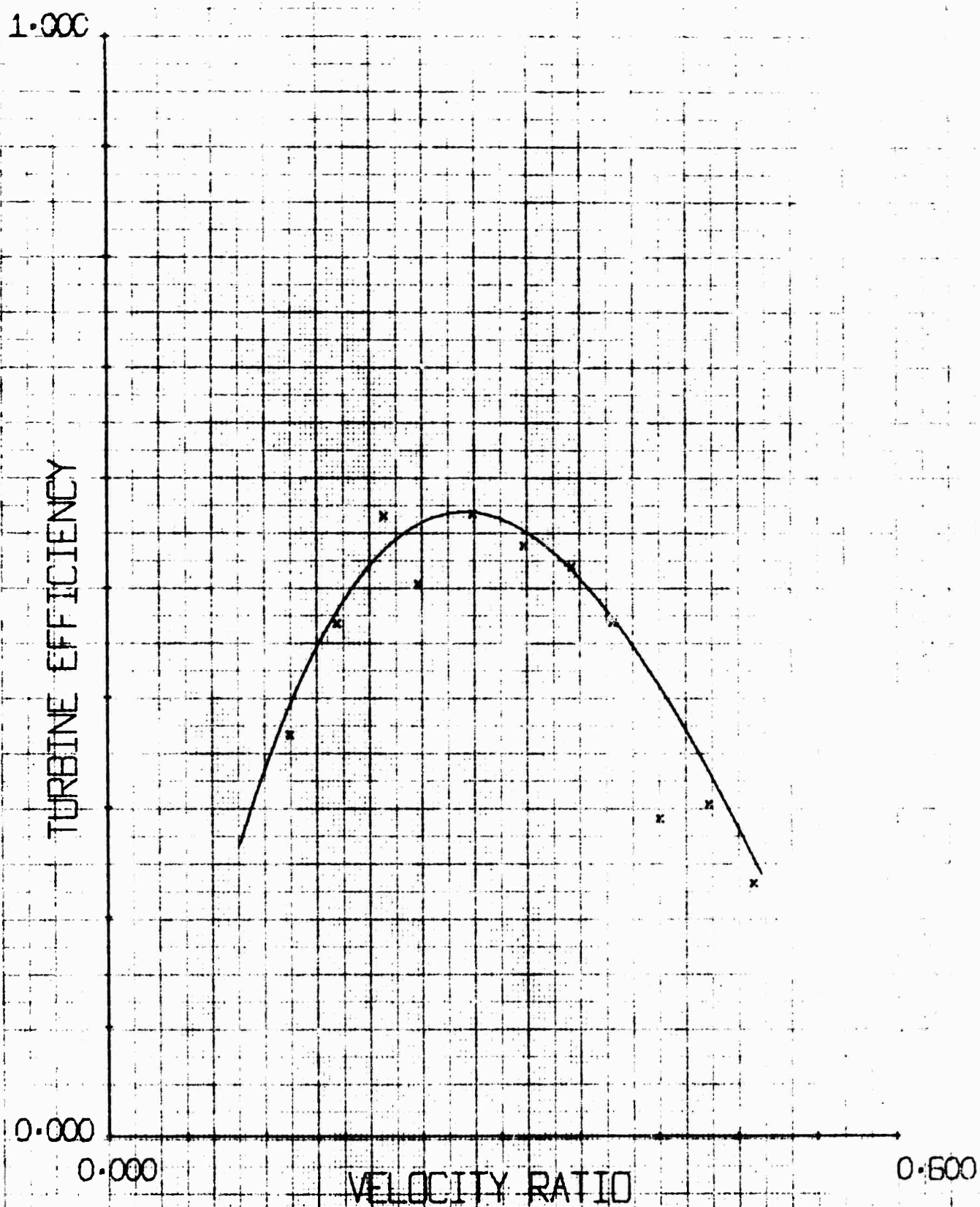
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VELOCITY RATIO

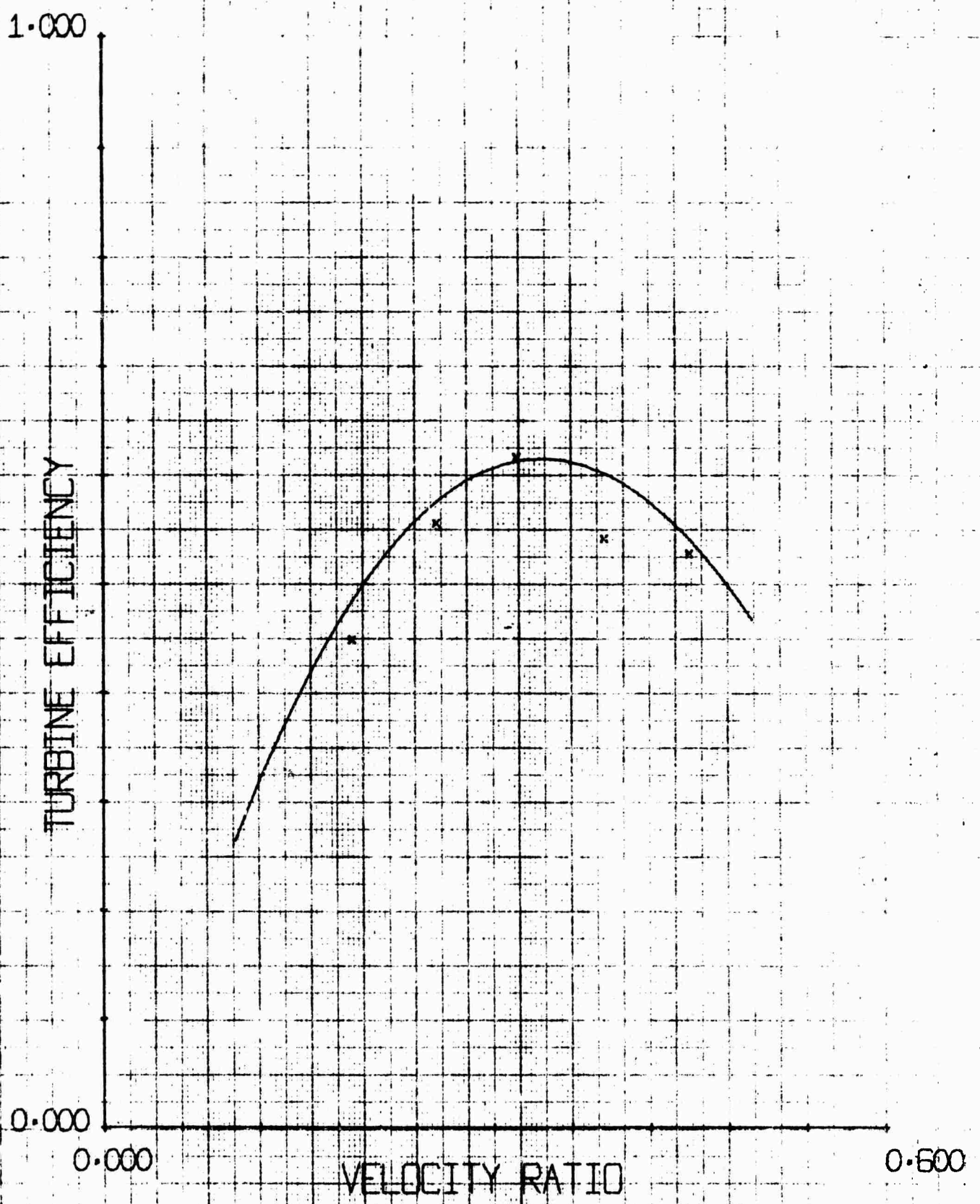
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MACH 2.5, PR. RATIO=15, HALF ANGLE=11





MACH 2.5, PR. RATIO=12, HALF ANGLE=11



MACH 2.5, PR. RATIO=25, HALF ANGLE=9

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TURBINE EFFICIENCY

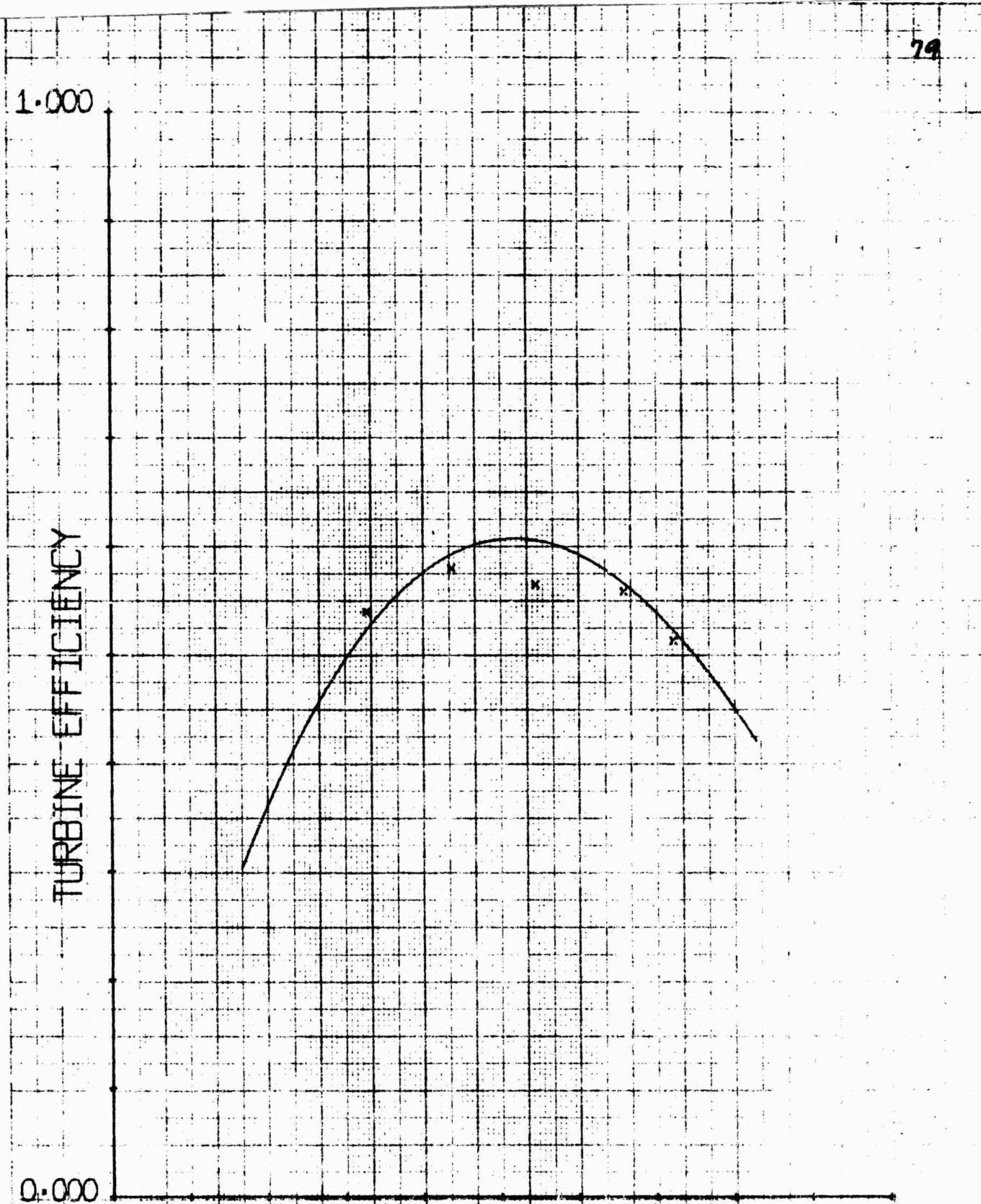
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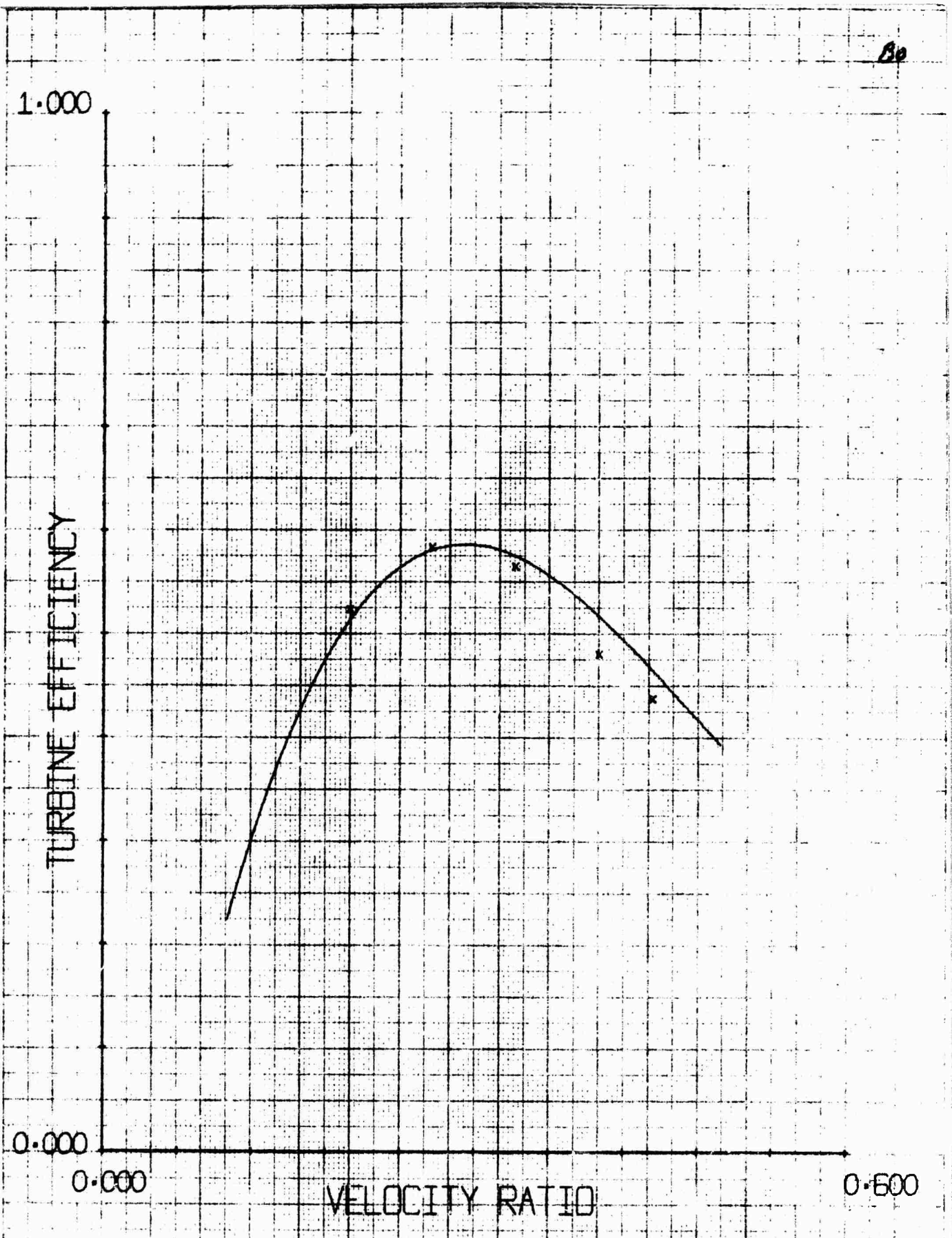
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0.600

MACH 2.5, PR. RATIO=20, HALF ANGLE=9







MACH 2.5, PR. RATIO=17, HALF ANGLE=9

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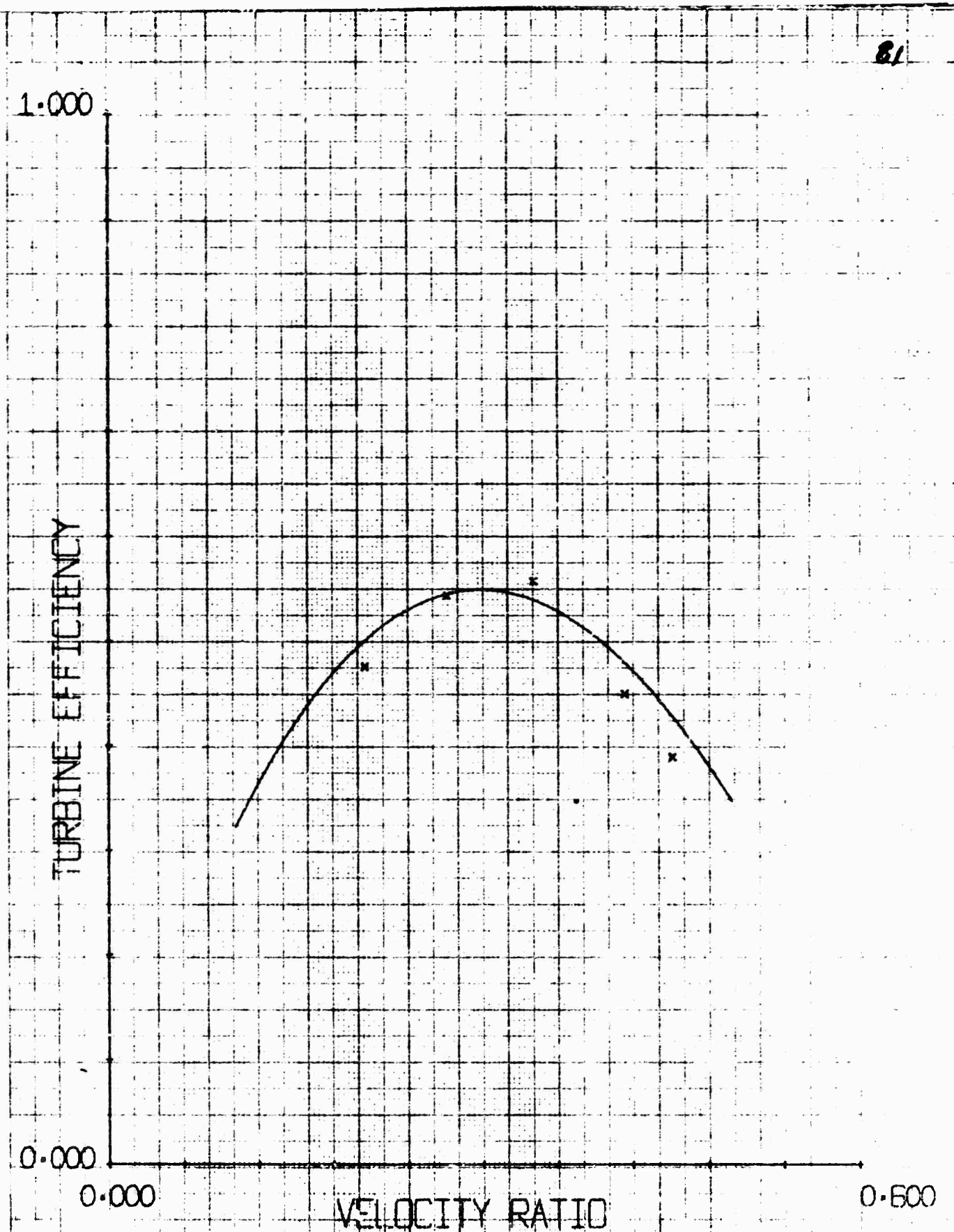
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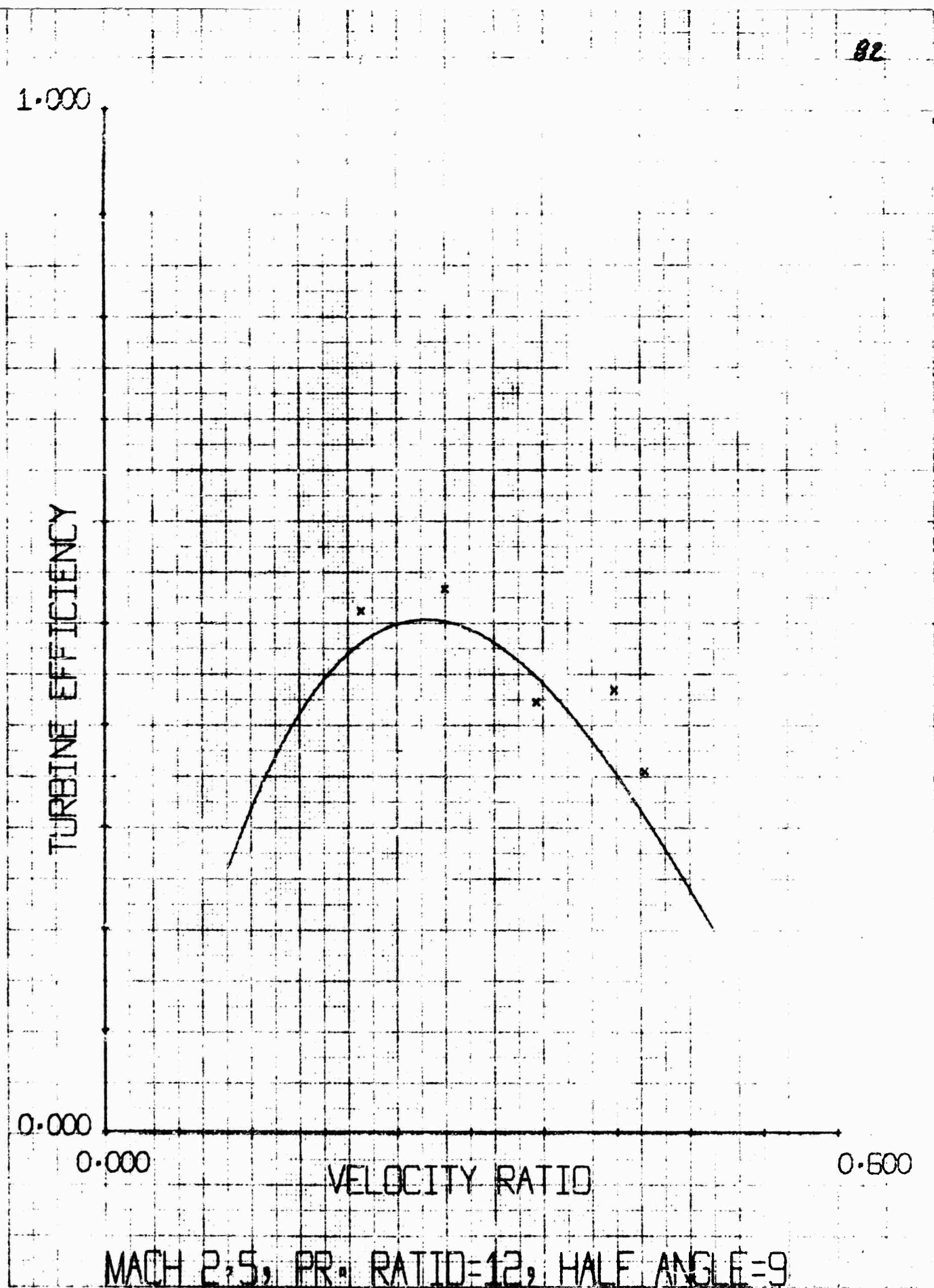
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MACH 2.5, PR. RATIO=12, HALF ANGLE=9



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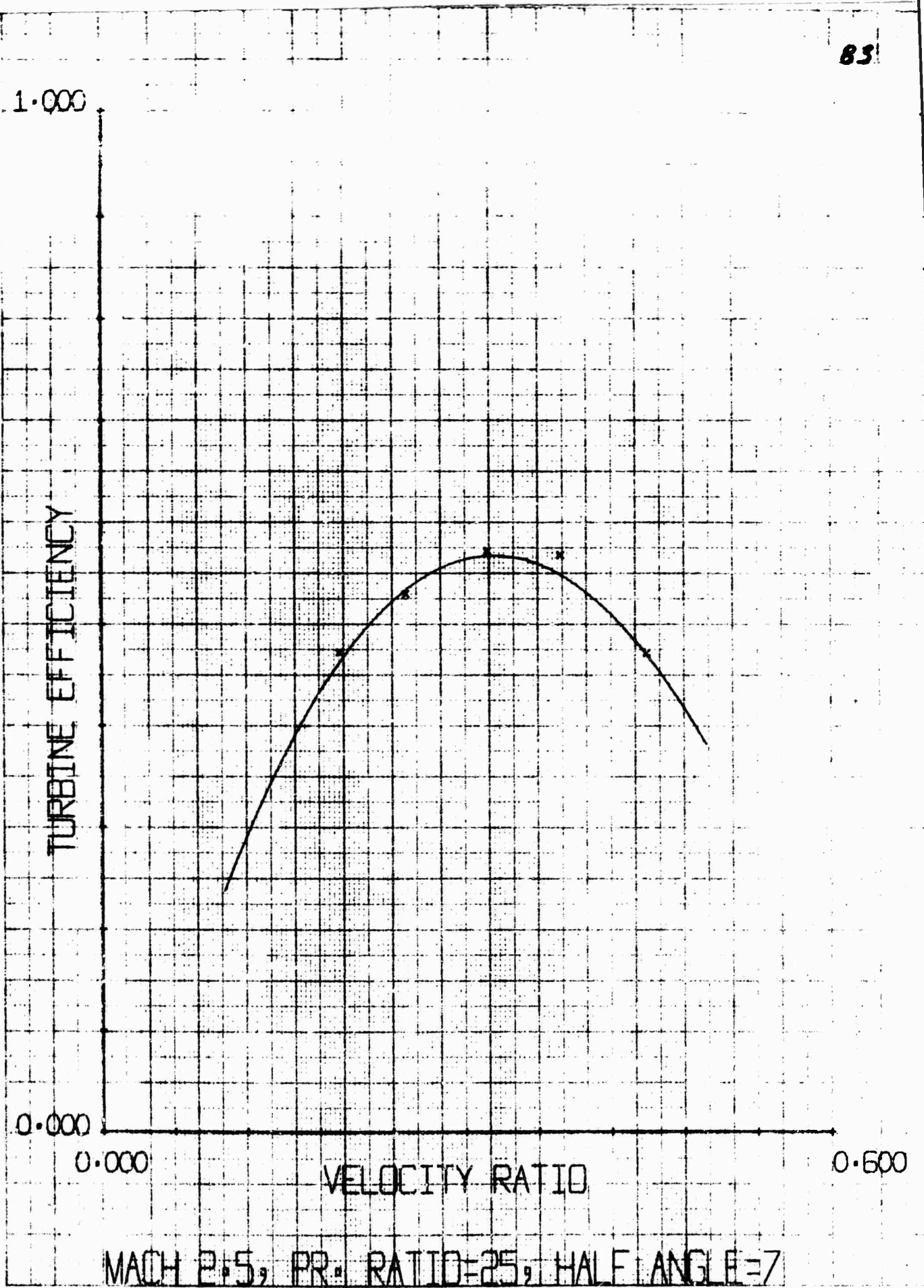
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=25, HALF ANGLE=7





1.000

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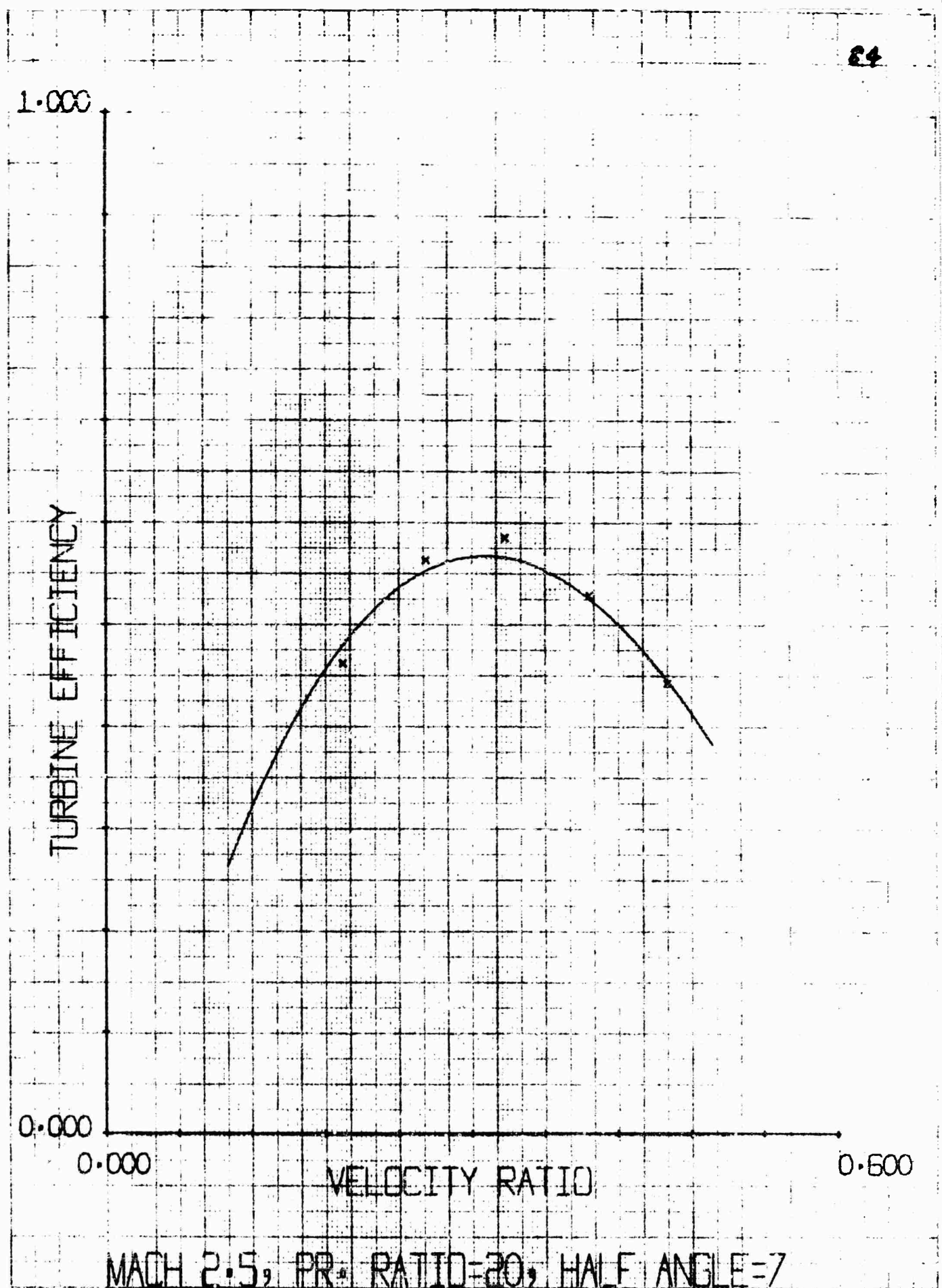
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=20, HALF ANGLE=7



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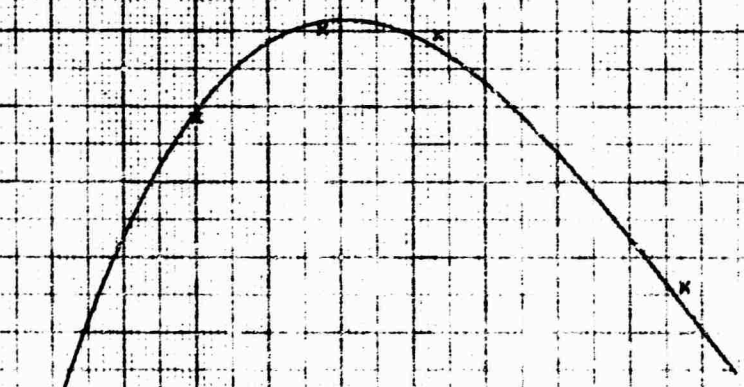
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=17, HALE ANGLE=7



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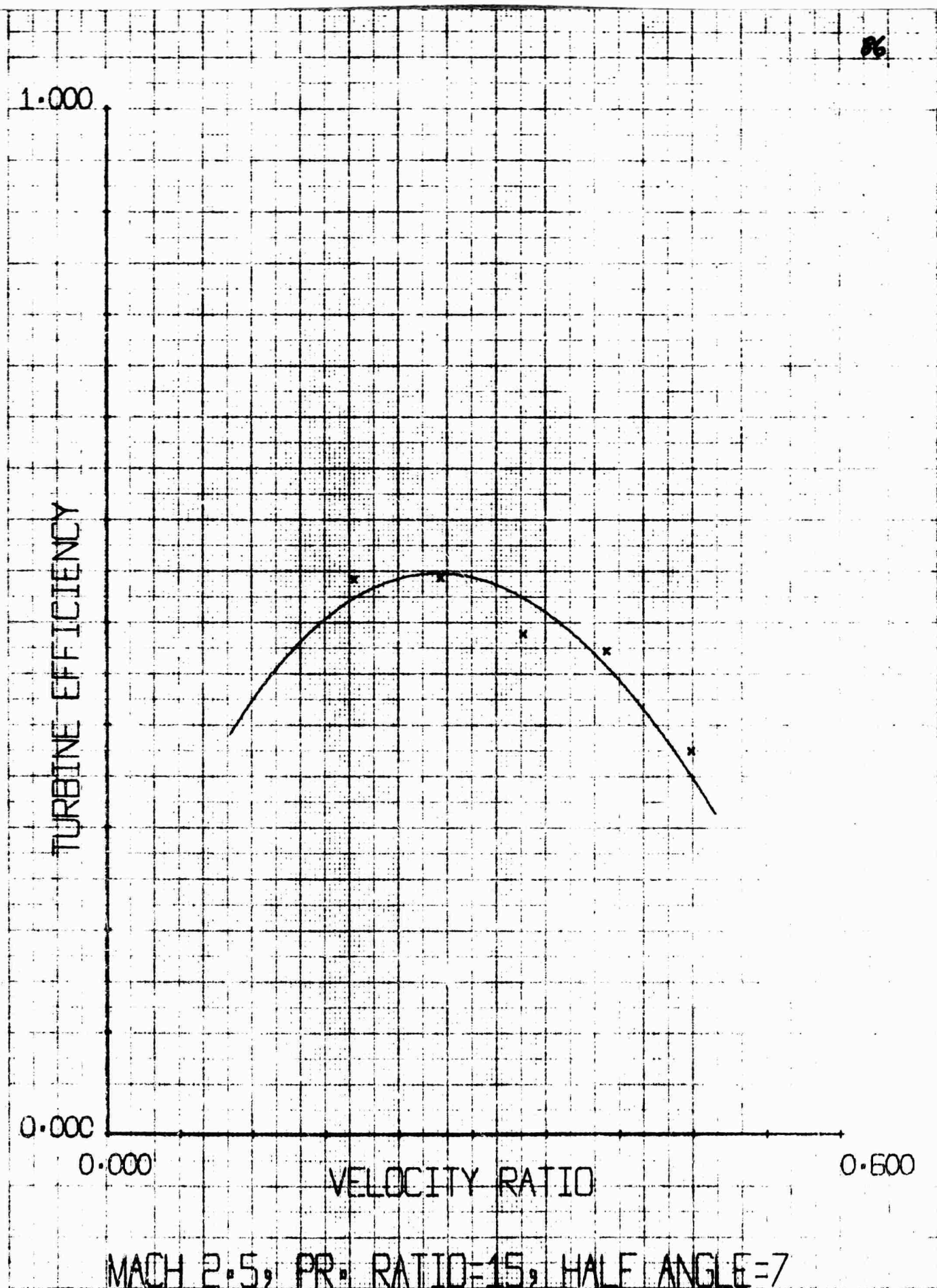
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MACH 2.5, PR. RATIO=15, HALF ANGLE=7



1.000

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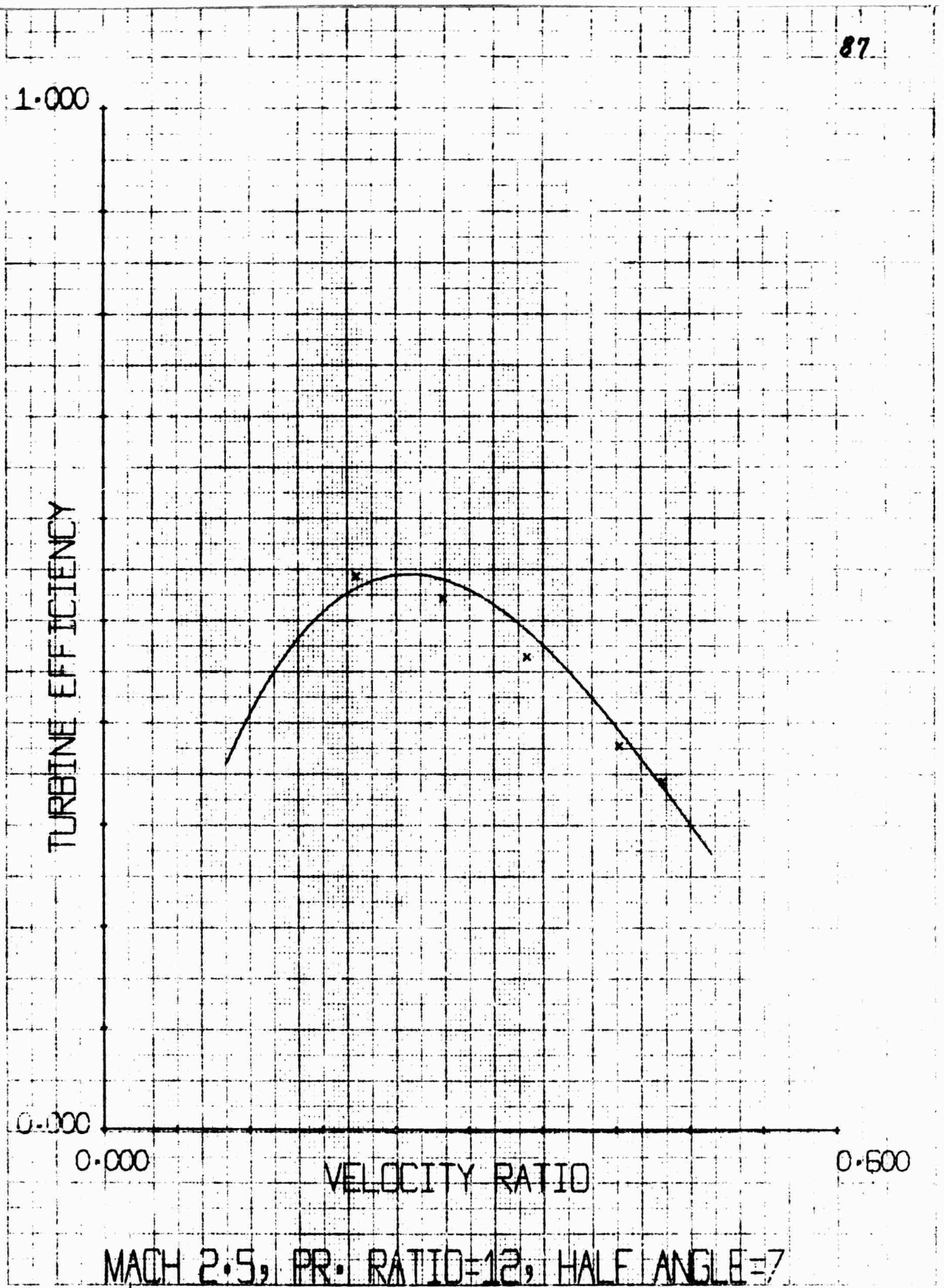
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VELOCITY RATIO

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MACH 2.5, PR. RATIO=12, HALF ANGLE=7





1.000

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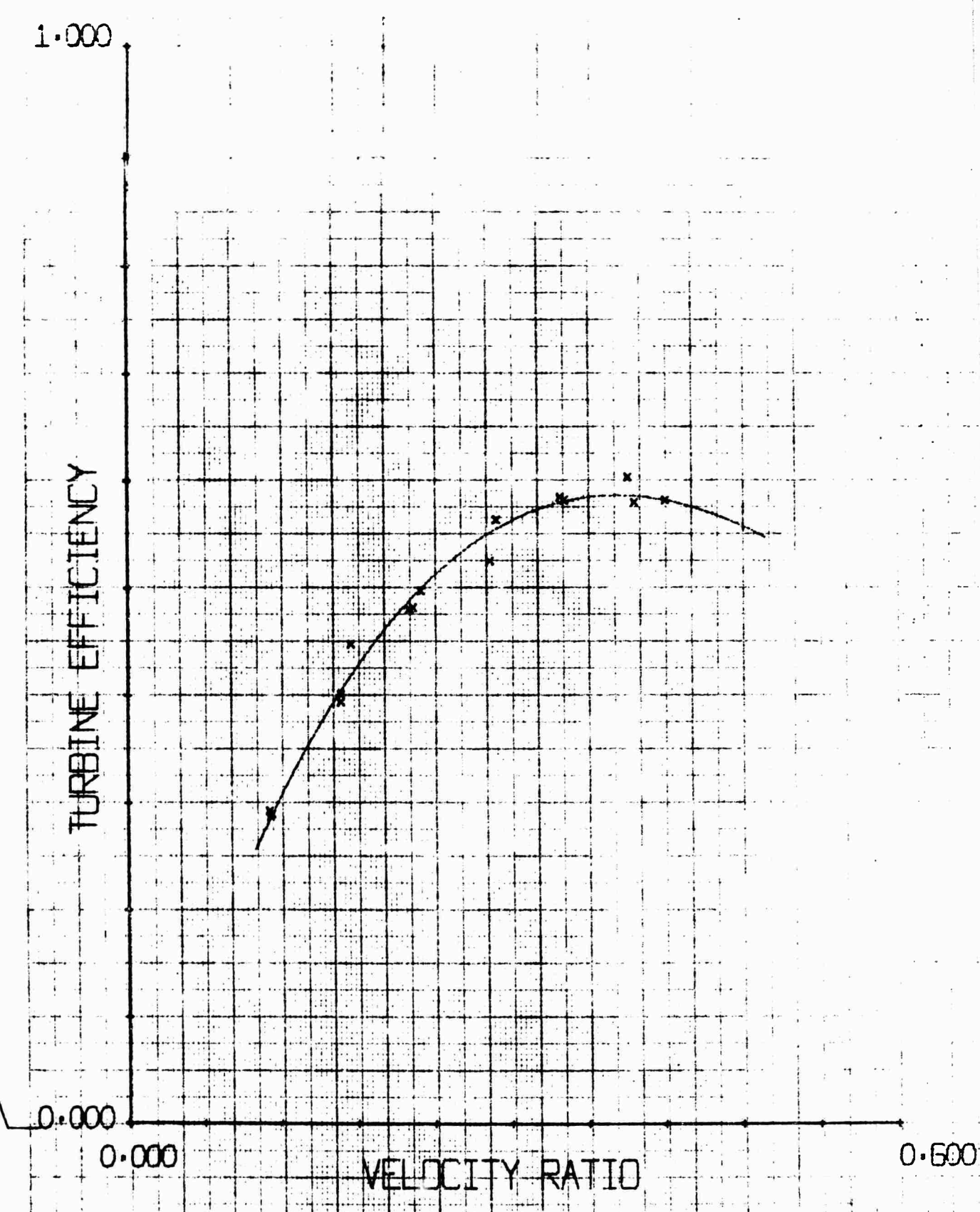
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MACH 4.0; PR. RATIO=200; HALF ANGLE=15



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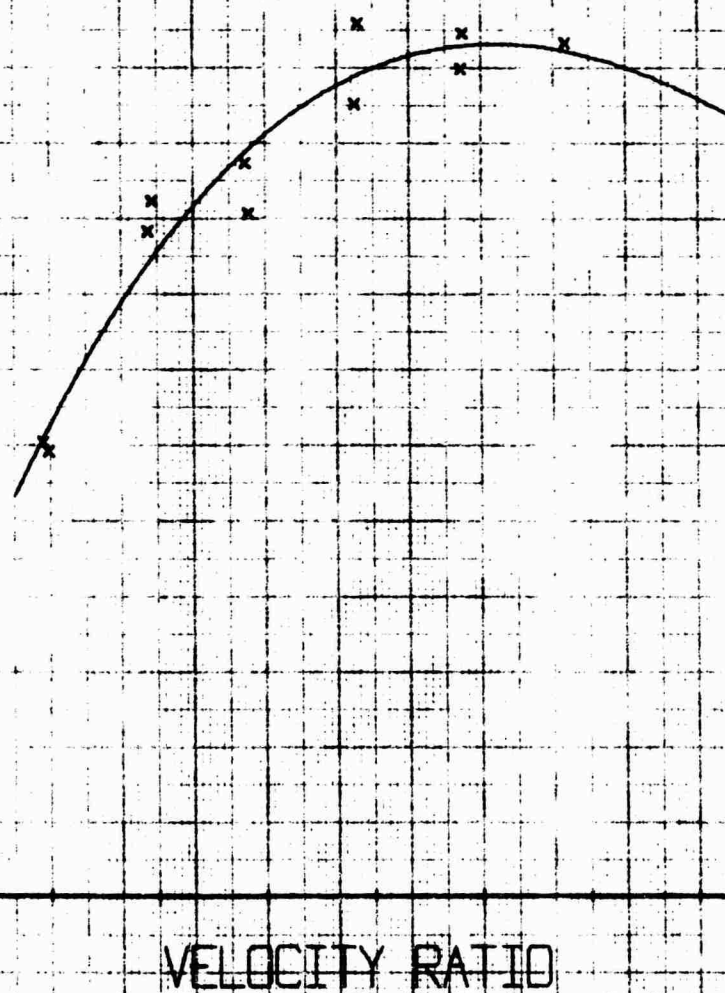
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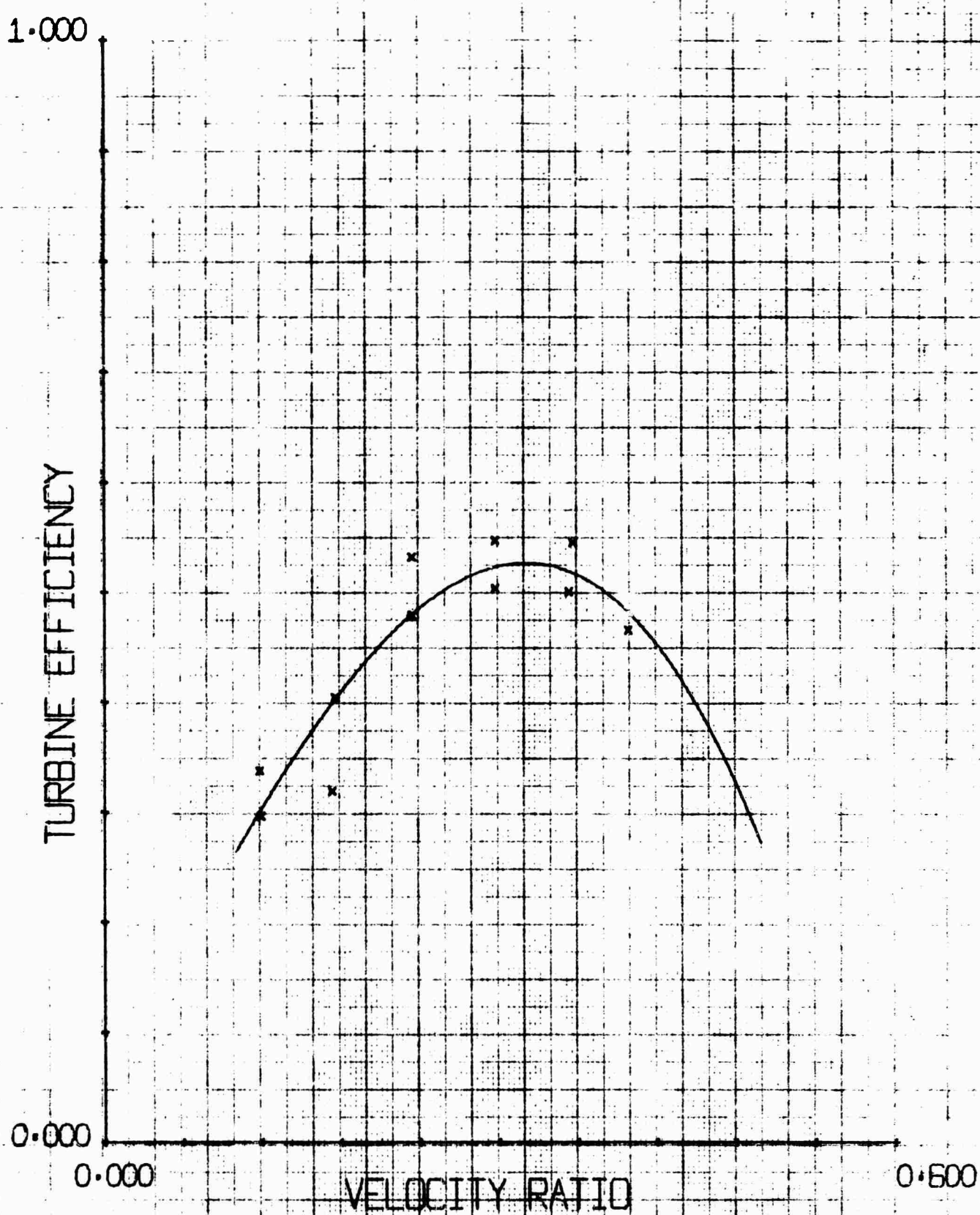
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VELOCITY RATIO

0.600

MACH 4.0, PR. RATIO=150, HALF ANGLE=15





MACH 4.0, PR. RATIO=100, HALF ANGLE=15

1.000

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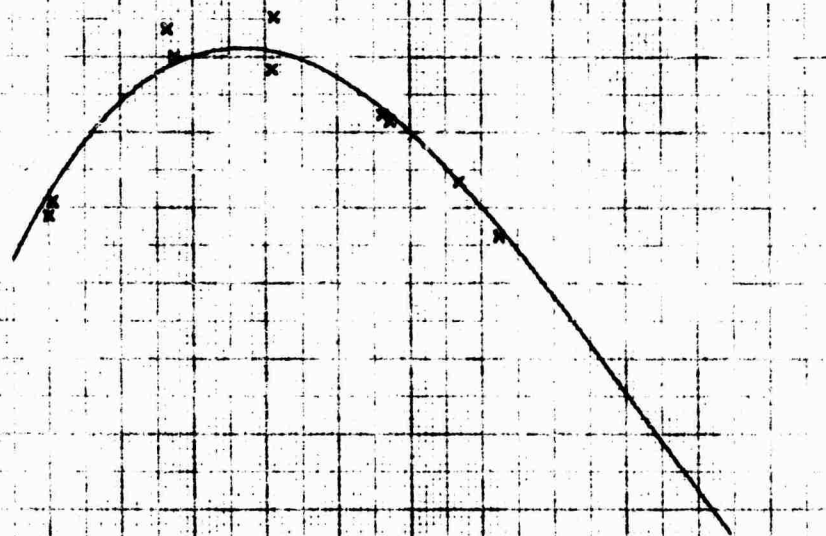
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=50, HALF ANGLE=15



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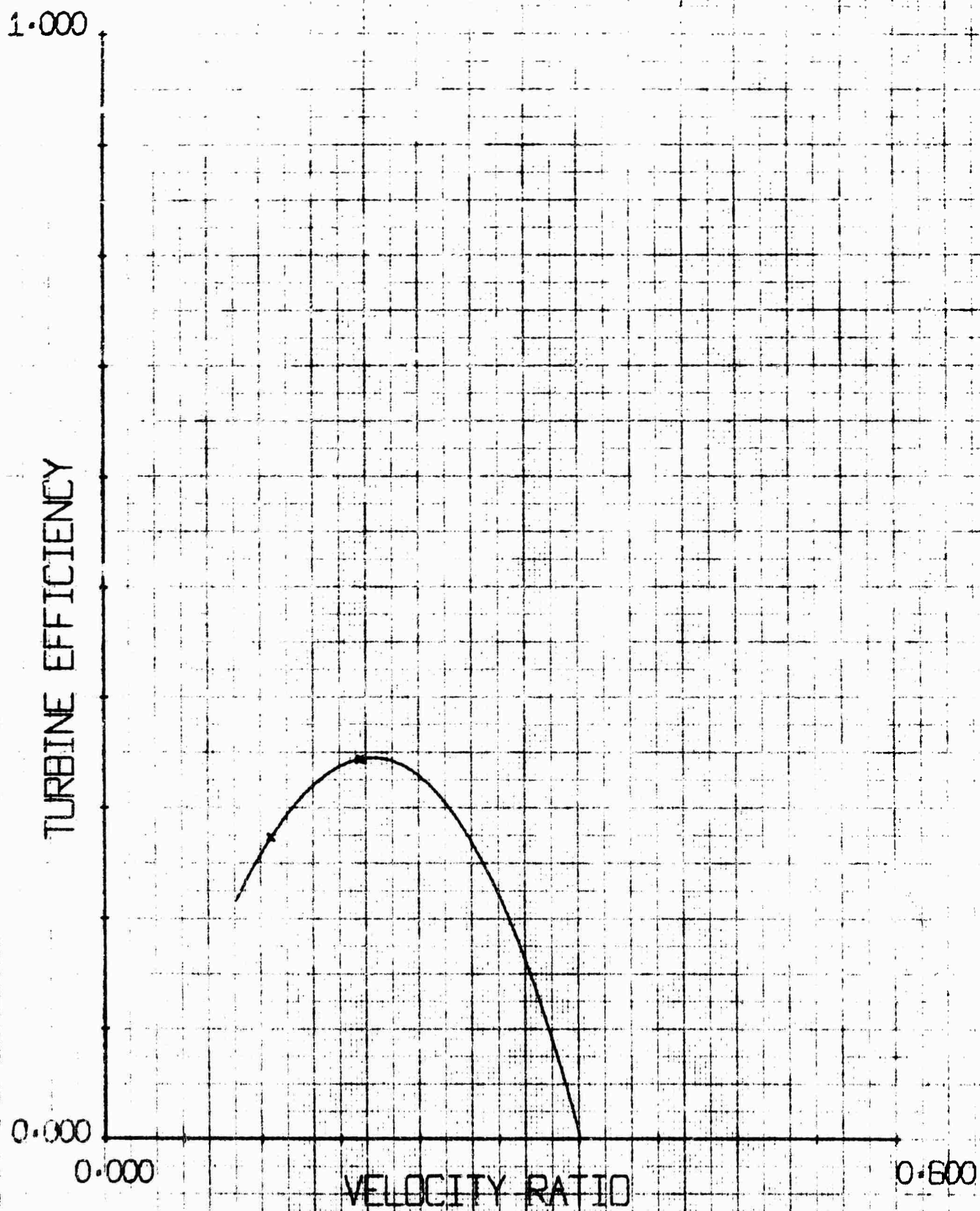
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=25, HALF ANGLE=15





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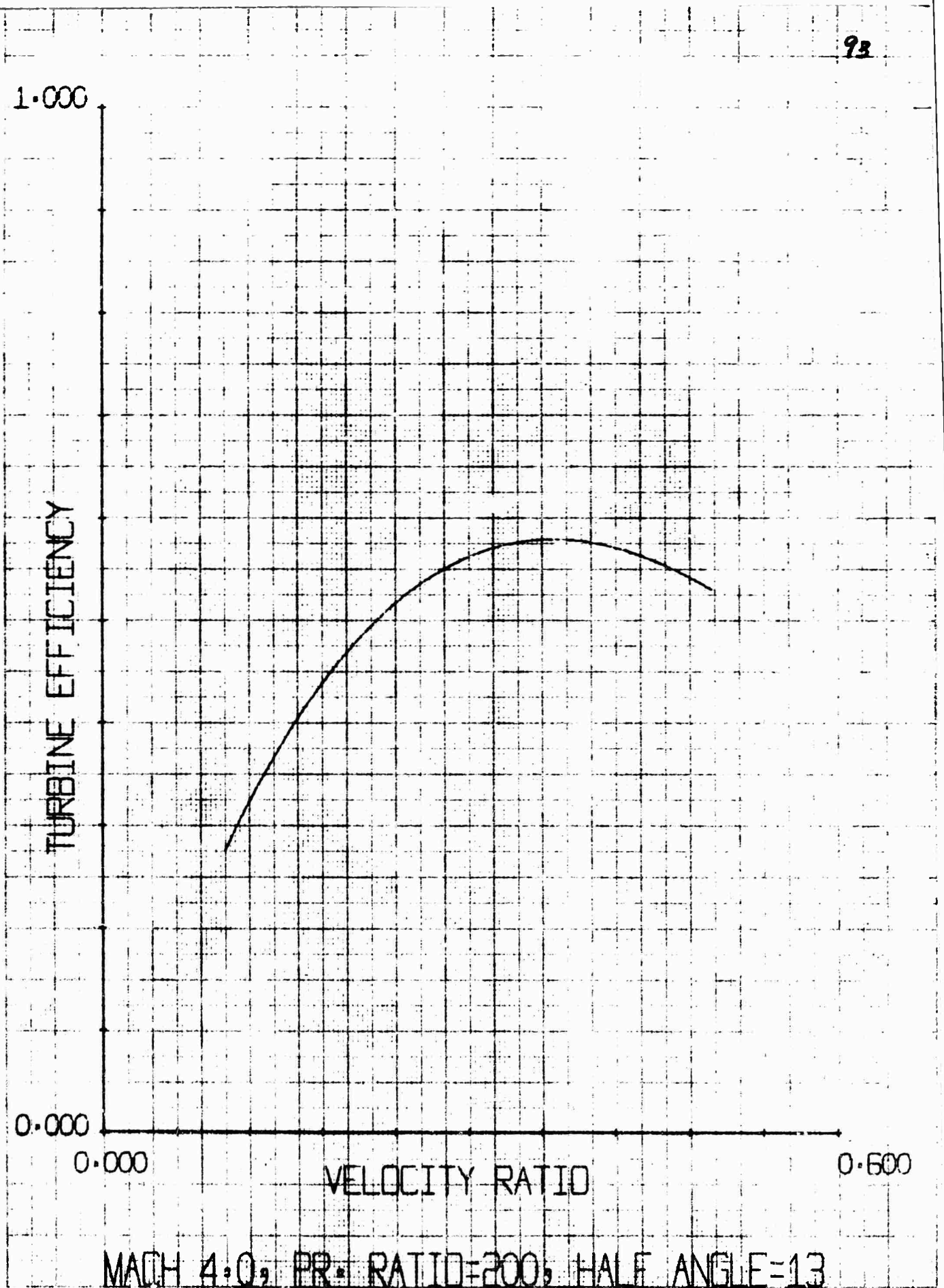
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=200, HALF ANGLE=13



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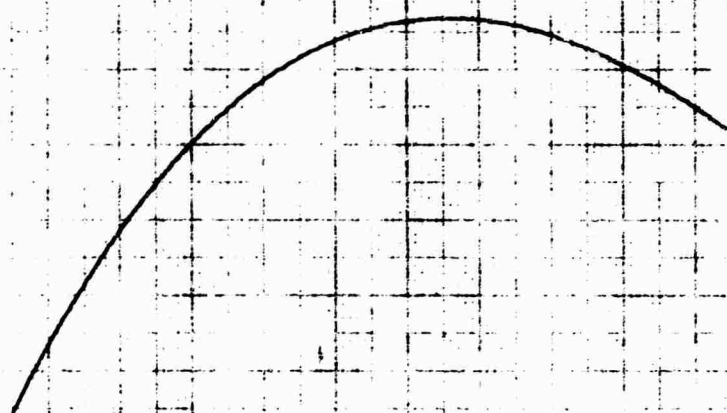
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=150, HALF ANGLE=13



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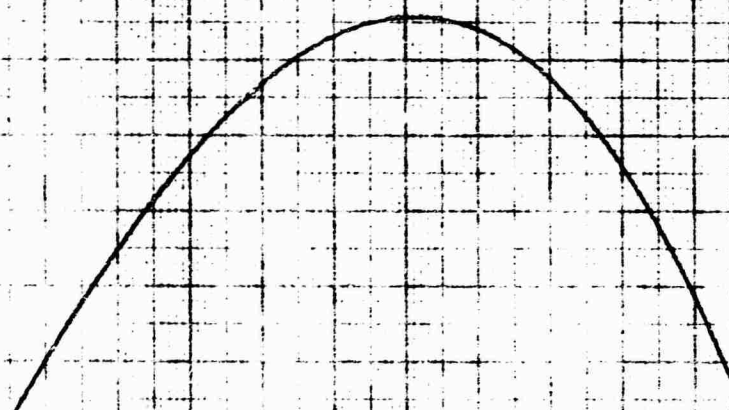
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=100, HALF ANGLE=13





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TURBINE EFFICIENCY

0.000

0.000

VELOCITY RATIO

0.600

MACH 4.0, PR. RATIO=50, HALF ANGLE=13

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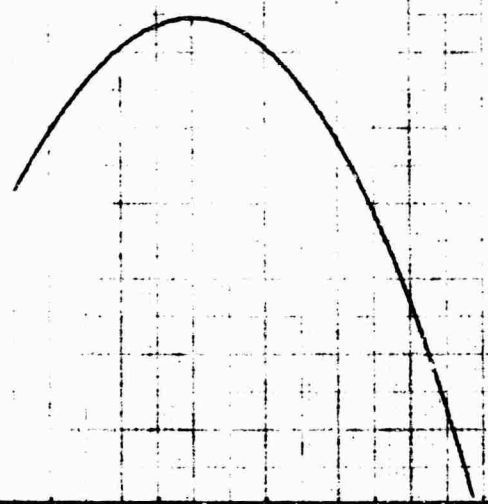
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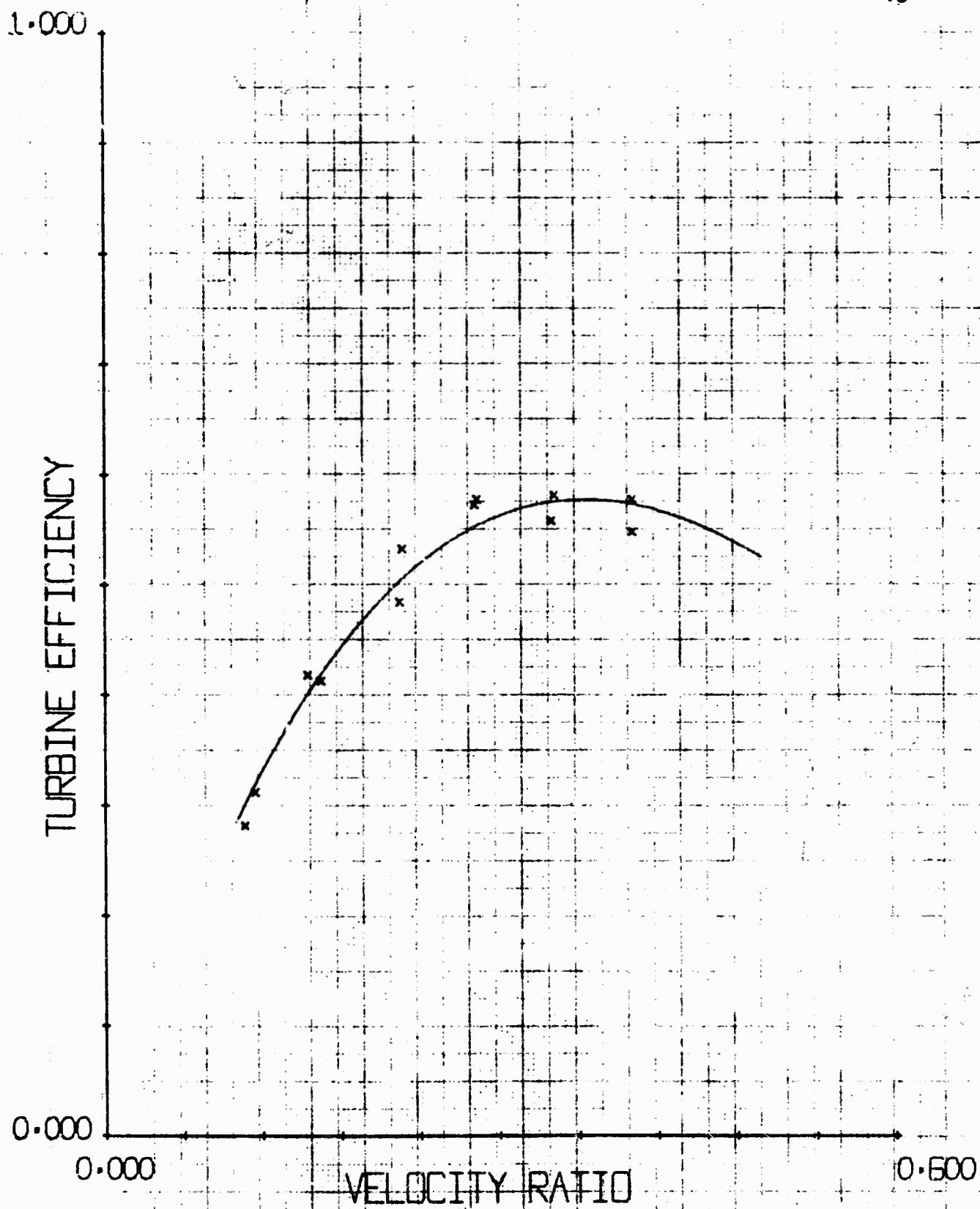
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VELOCITY RATIO

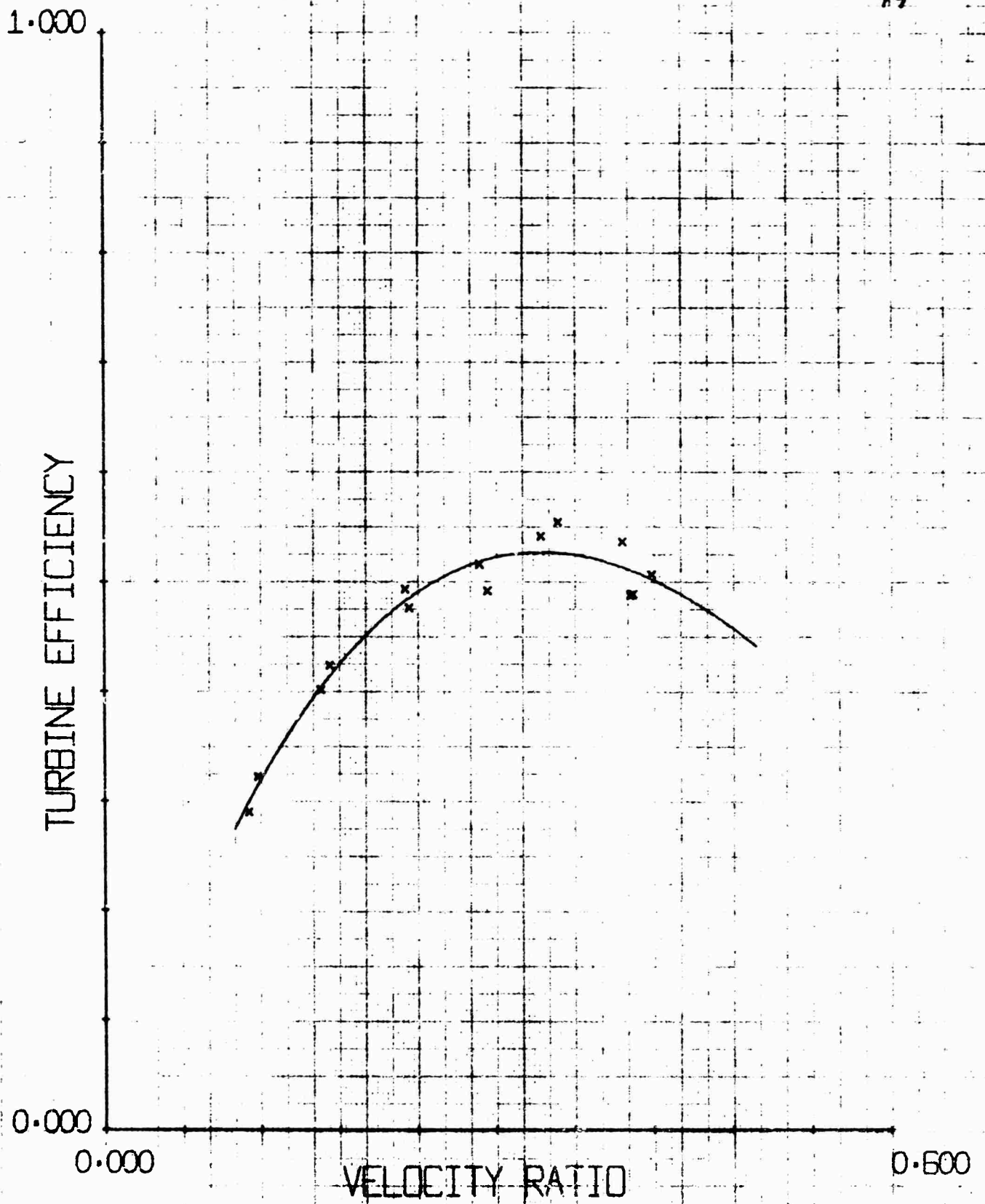
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MACH 4.0, PR. RATIO=25, HALF ANGLE=13





MACH 4.0, PR. RATIO=200, HALF ANGLE=11



MACH 4.0, PR. RATIO=150, HALF ANGLE=11

1.000

100

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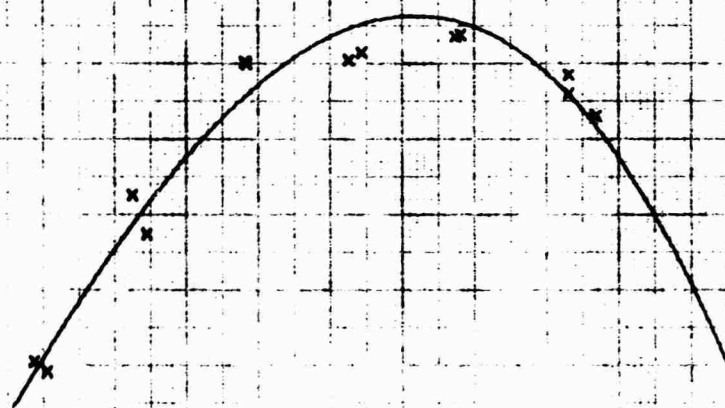
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=100, HALF ANGLE=11



1.000

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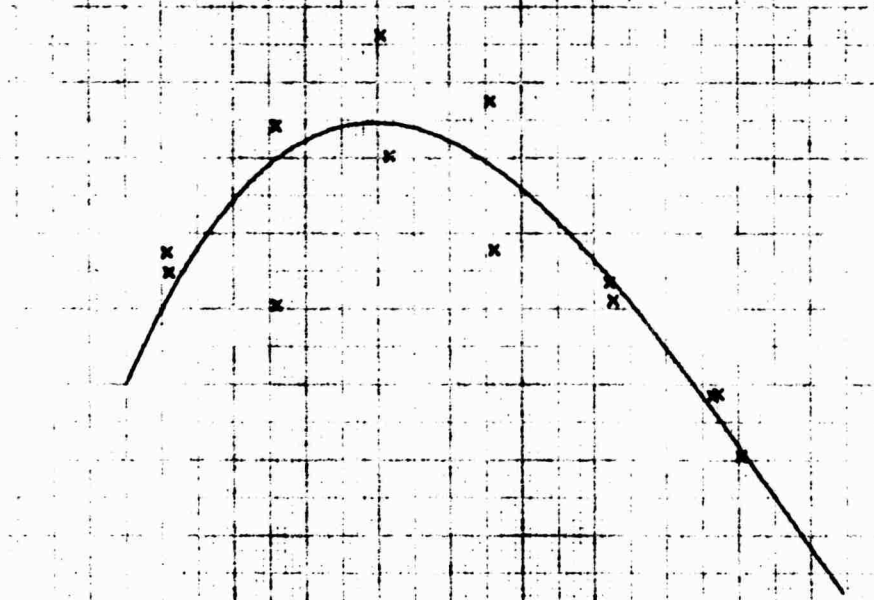
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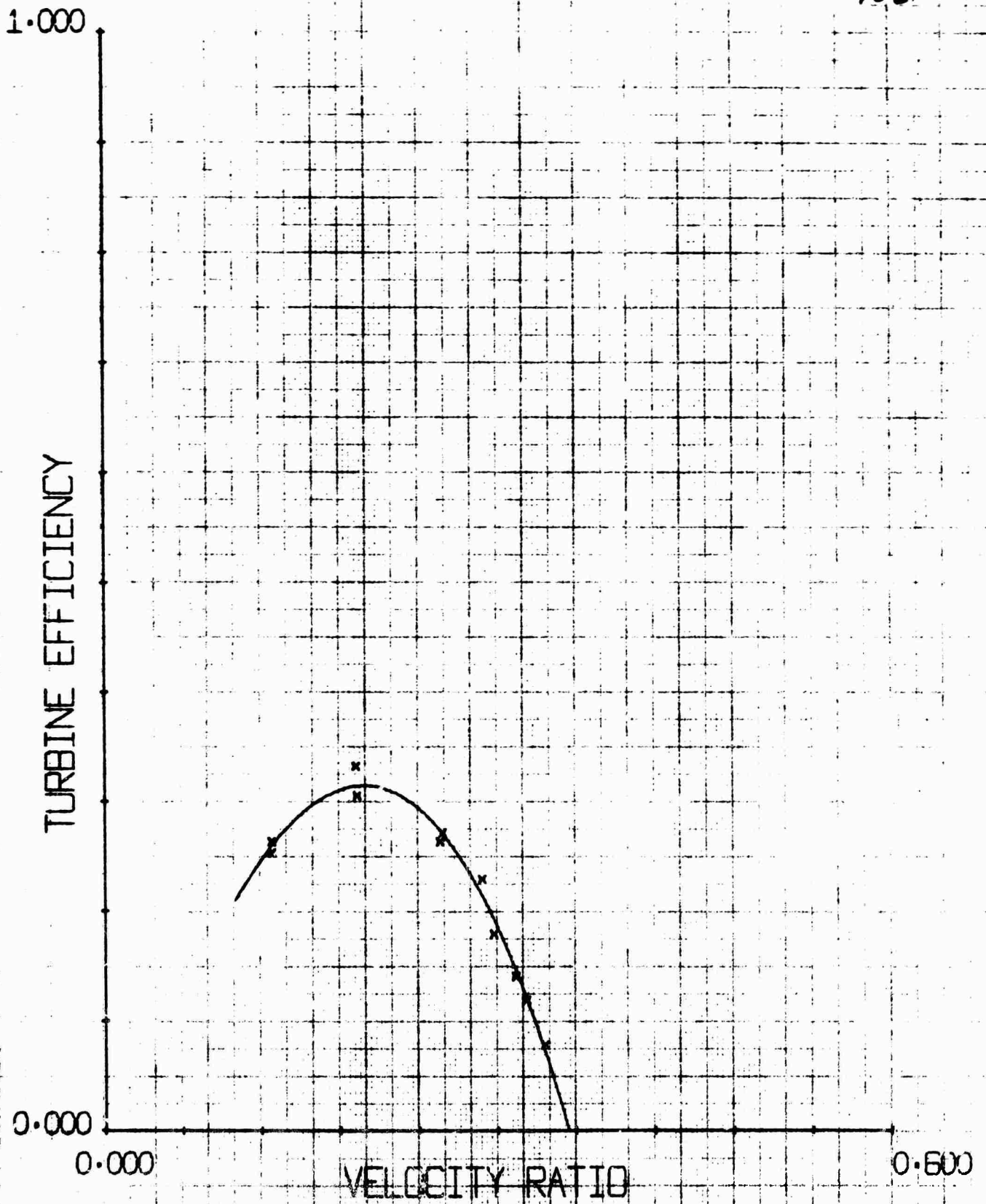
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=50, HALF ANGLE=11





MACH 4.0, PR: RATIO=25, HALF ANGLE=11



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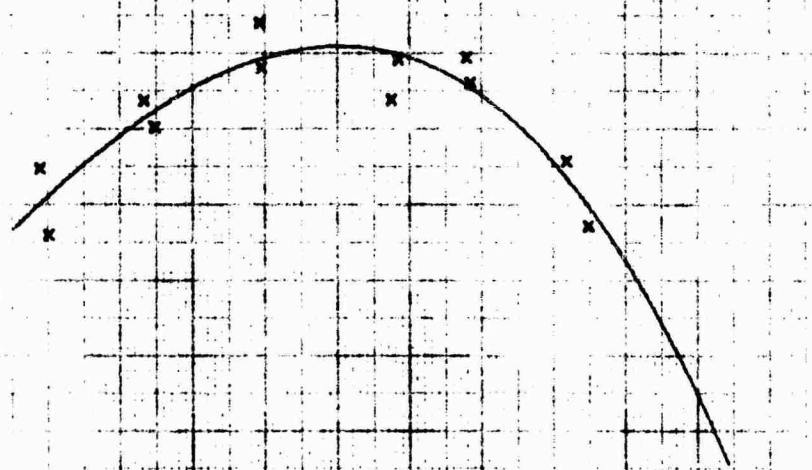
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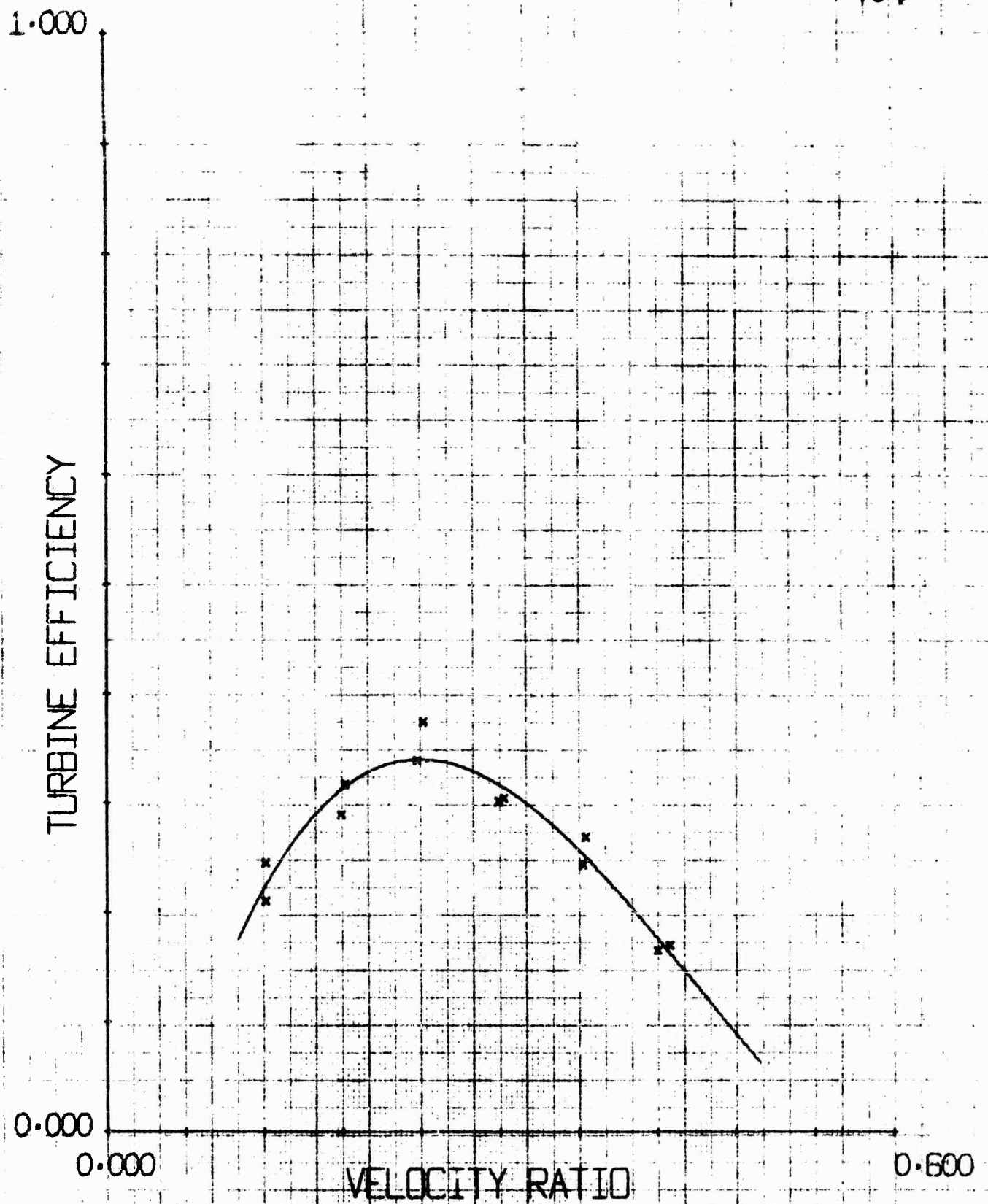
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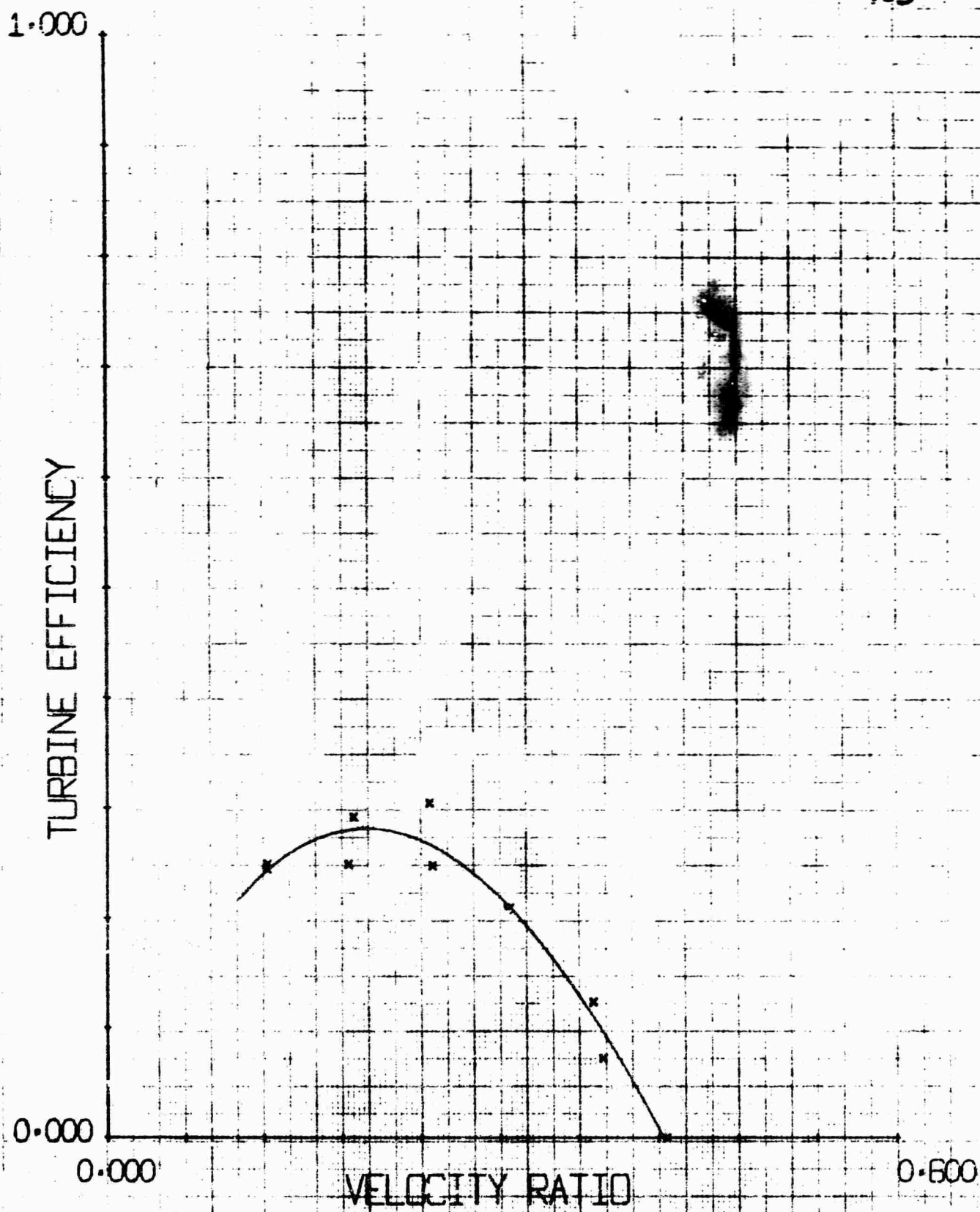
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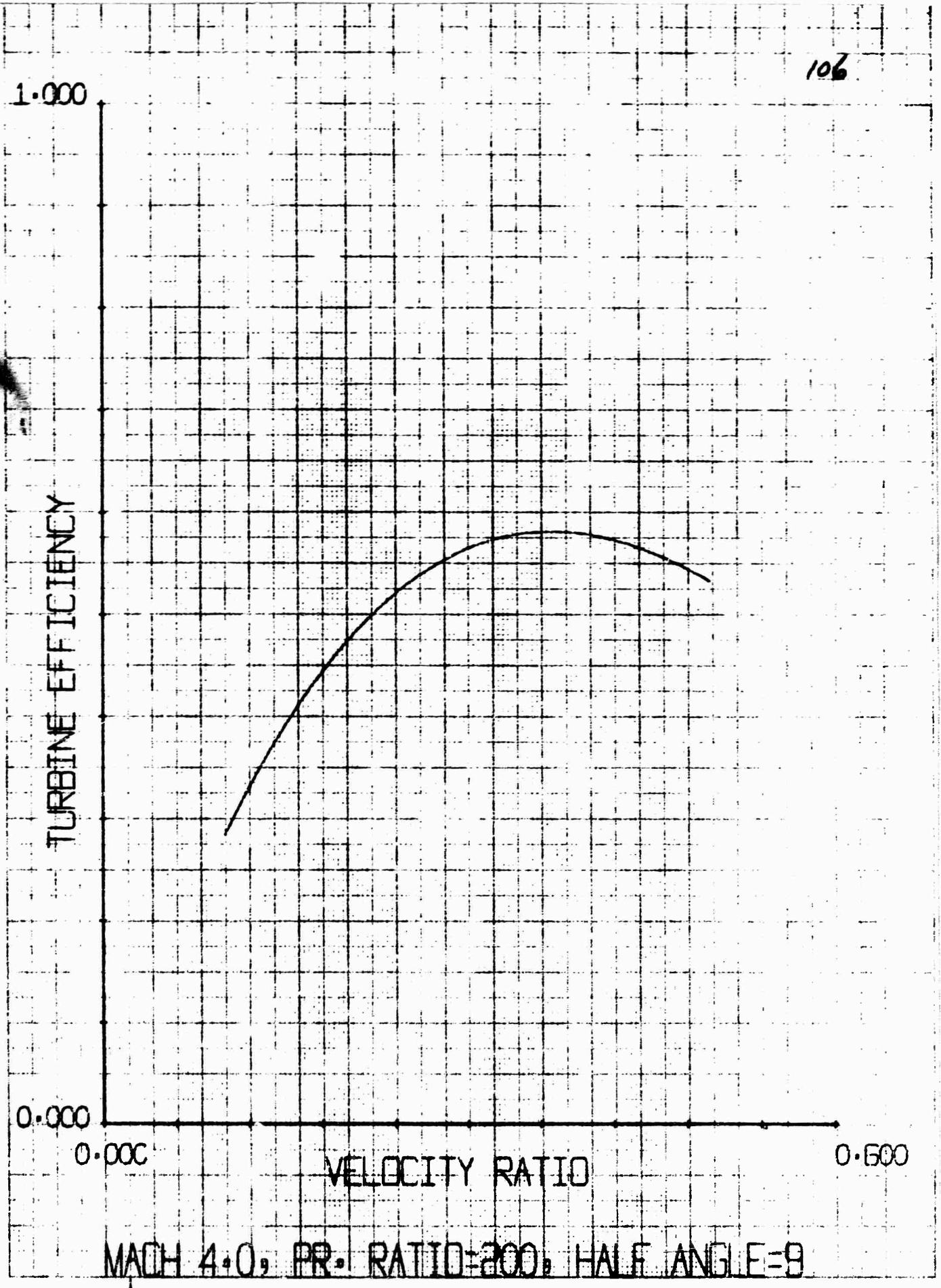




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MACH 4.0, PR. RATIO=200, HALF ANGLE=8

1.000

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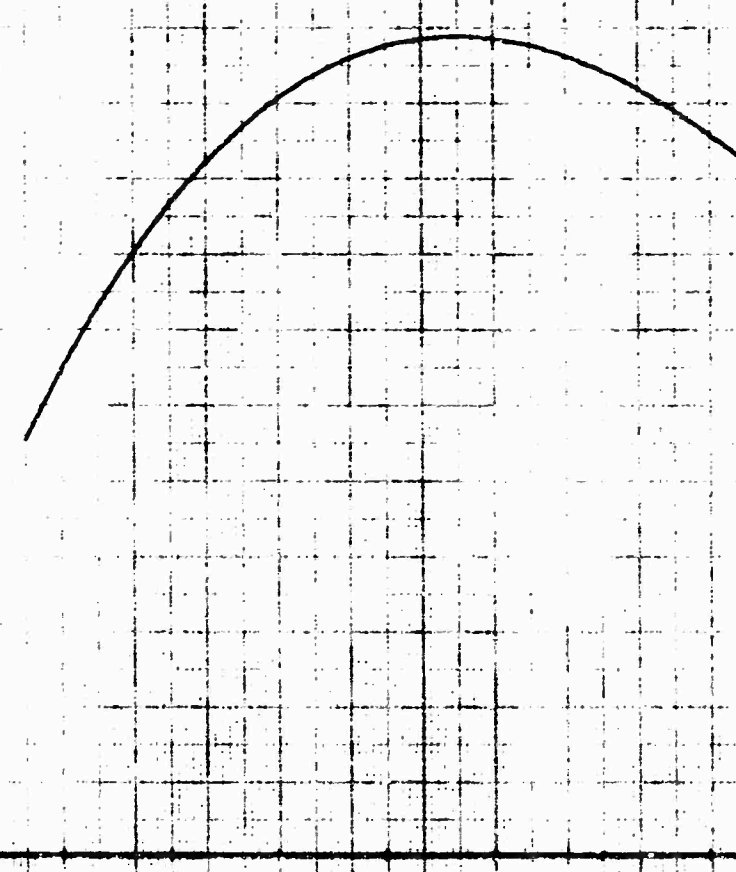
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=150, HALF ANGLE=9



1.000

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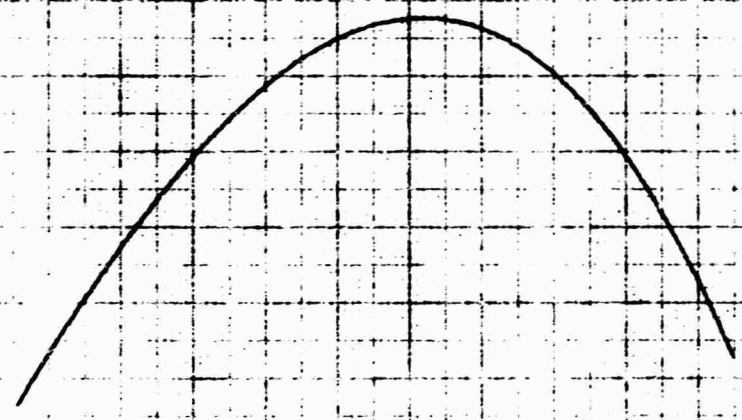
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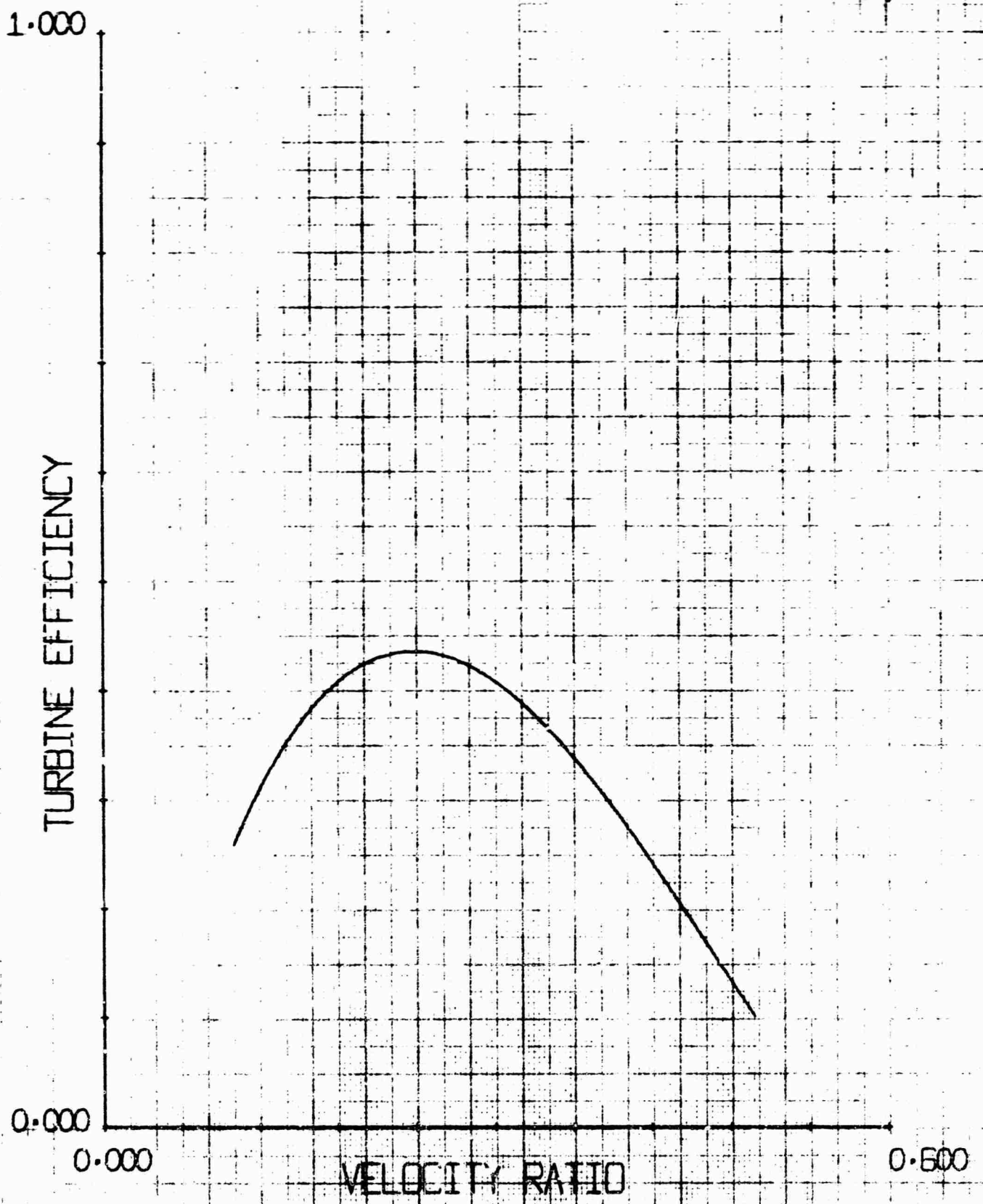
VELOCITY RATIO

0.600

MACH 4.0, PR. RATIO=100, HALF ANGLE=3







MACH 4.0, PR. RATIO=50, HALF ANGLE=9

1.000

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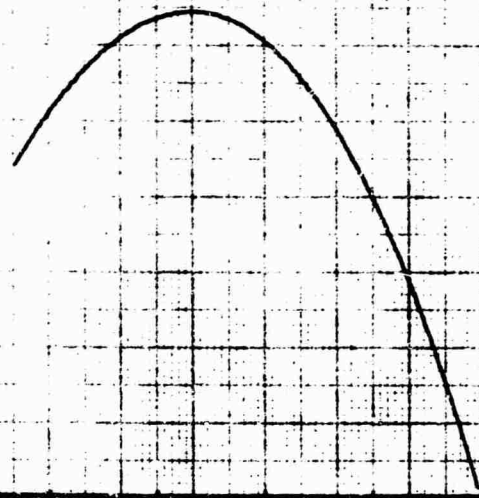
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VELOCITY RATIO

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MACH 4.0, PR. RATIO=25, HALF ANGLE=9





1.000

TURBINE EFFICIENCY

0.000

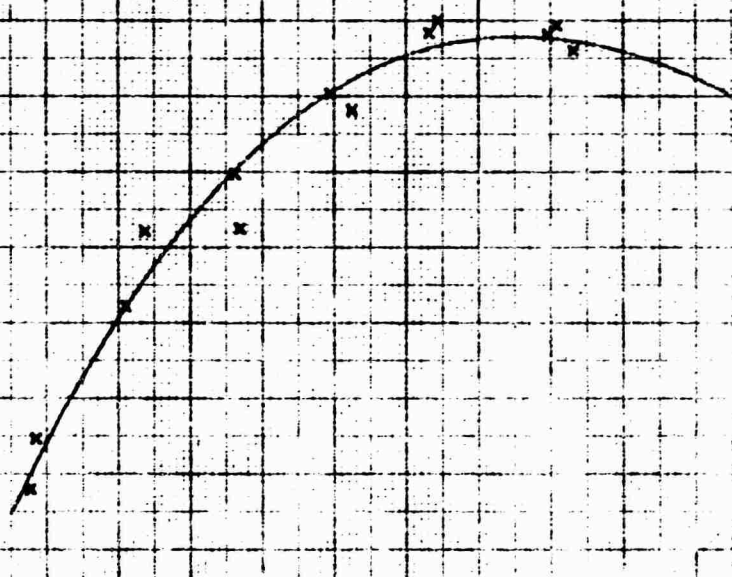
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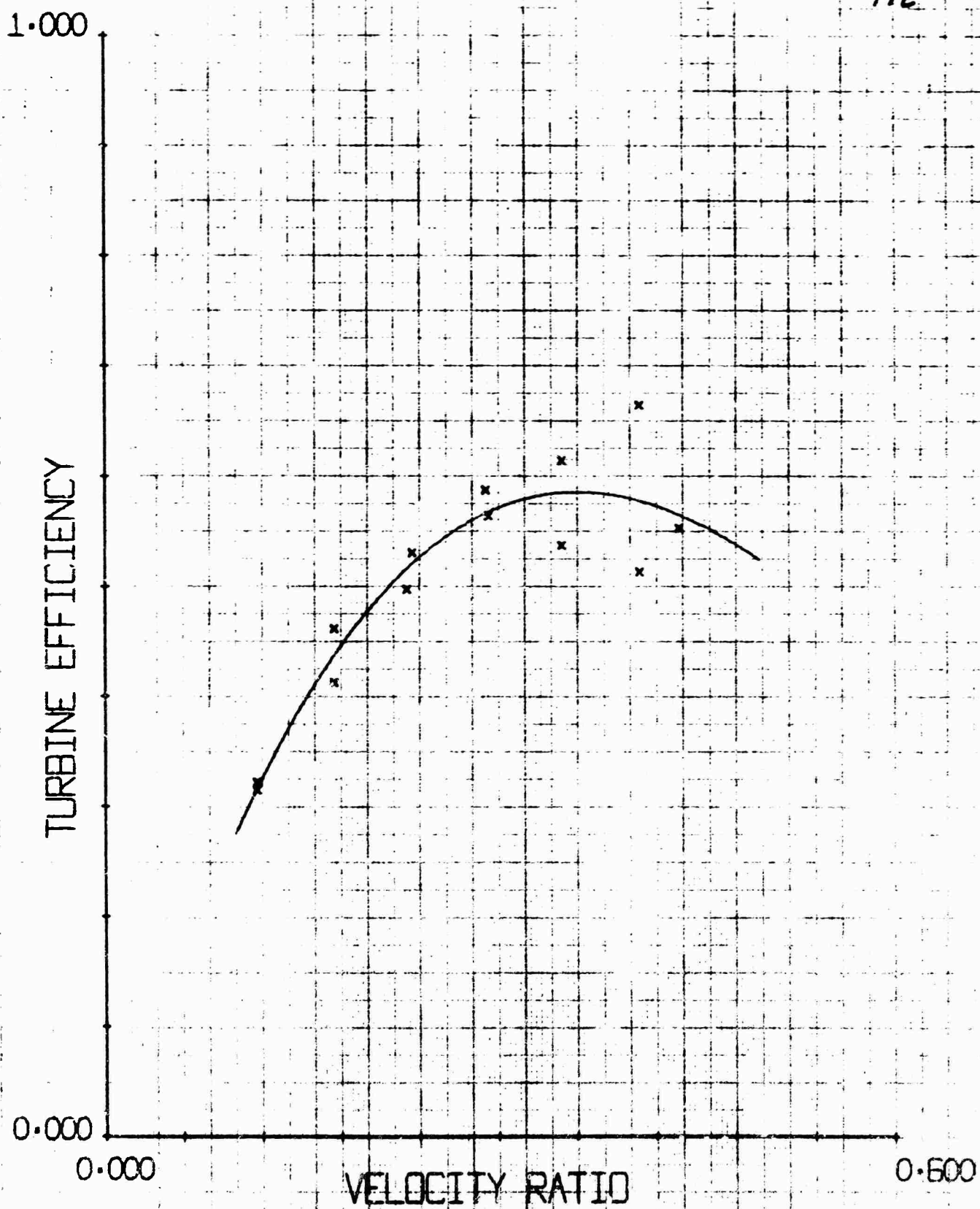
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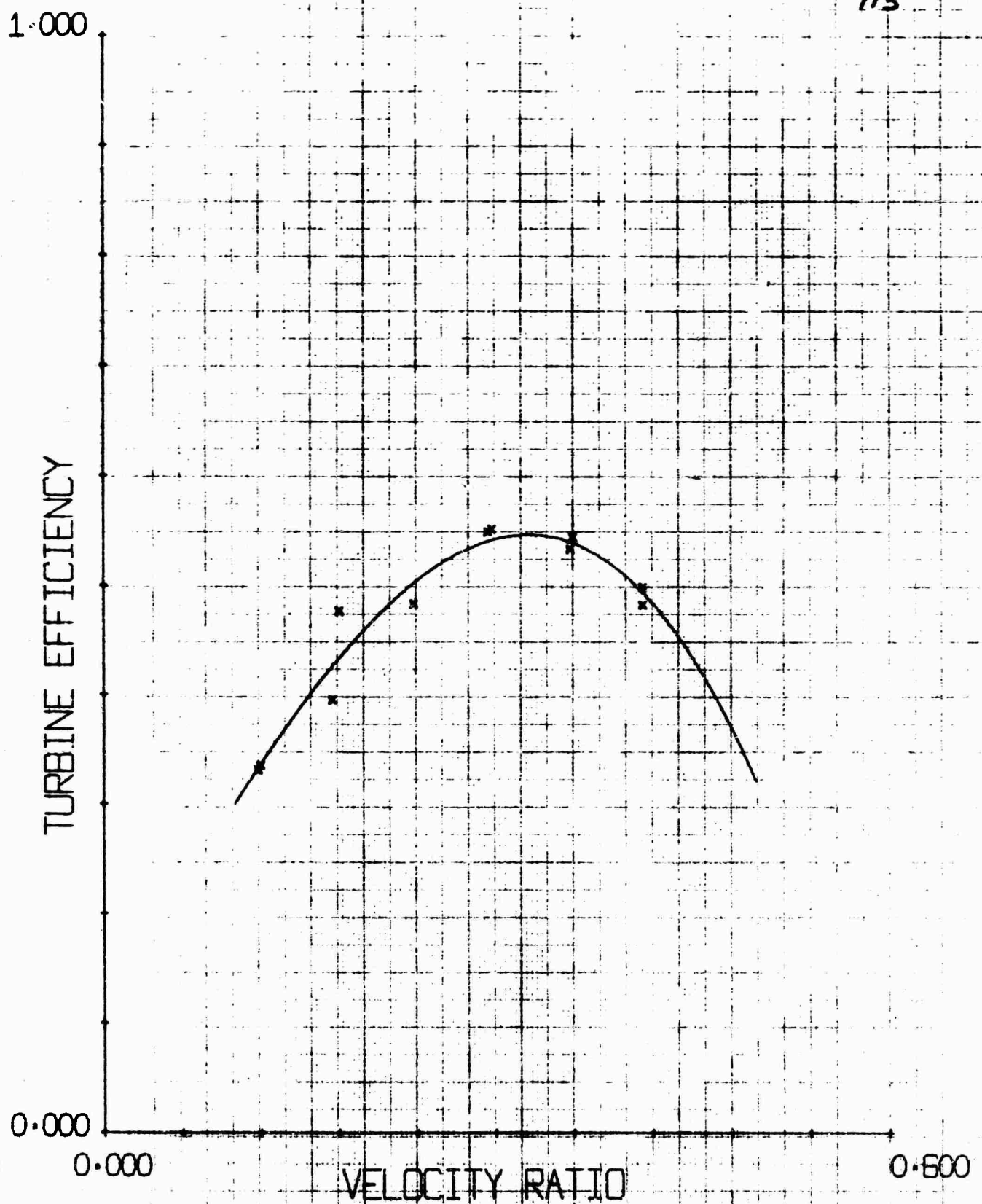
MACH 4.0, PR. RATIO=200, HALF ANGLE=7

111





MACH 4.0, PR. RATIO=150, HALF ANGLE=7



MACH 4.0, PR. RATIO=100, HALF ANGLE=7

1.000

TURBINE EFFICIENCY

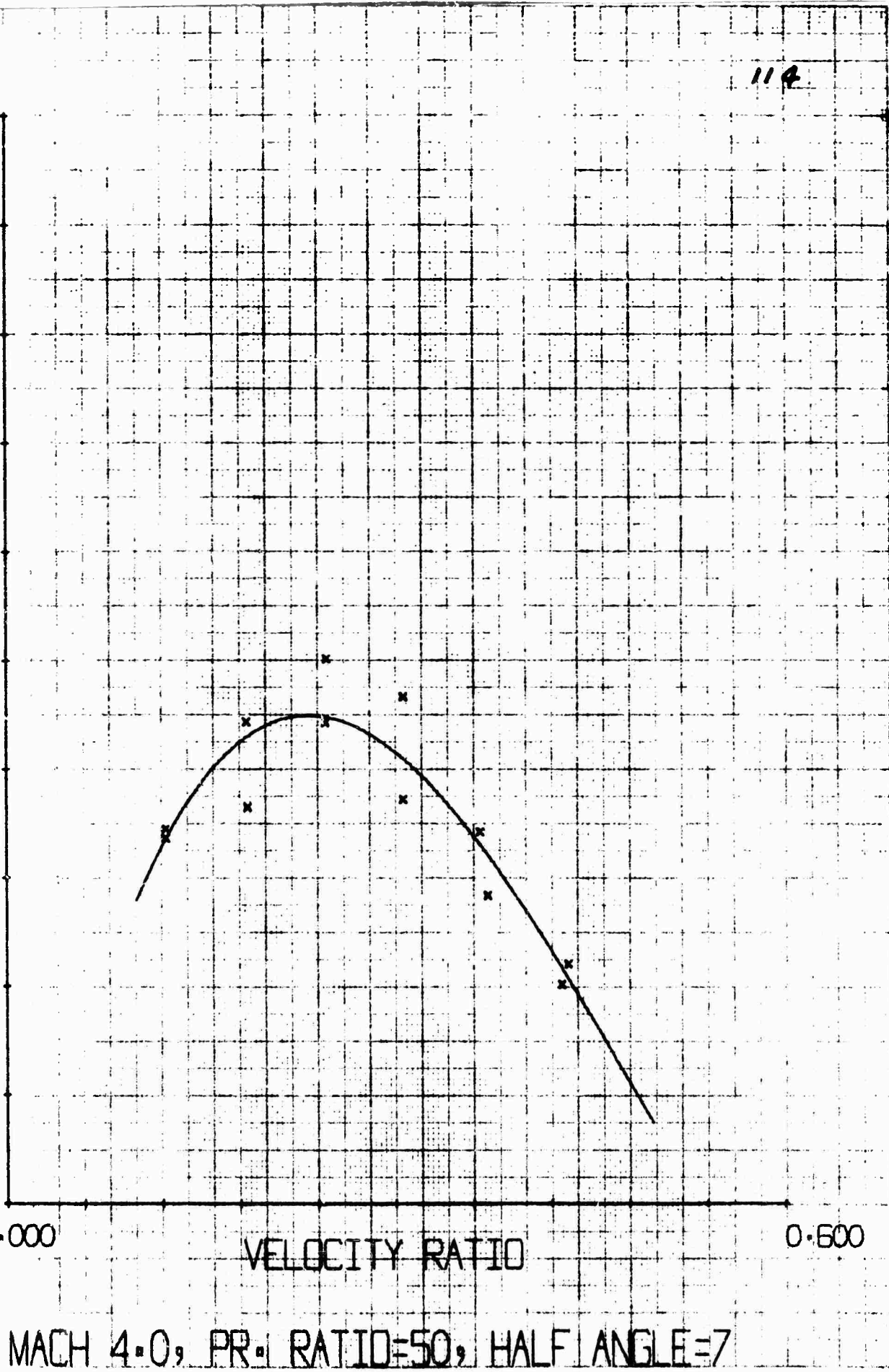
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VELOCITY RATIO

0.600

MACH 4.0, PR. RATIO=50, HALF ANGLE=7



115

1.000

TURBINE EFFICIENCY

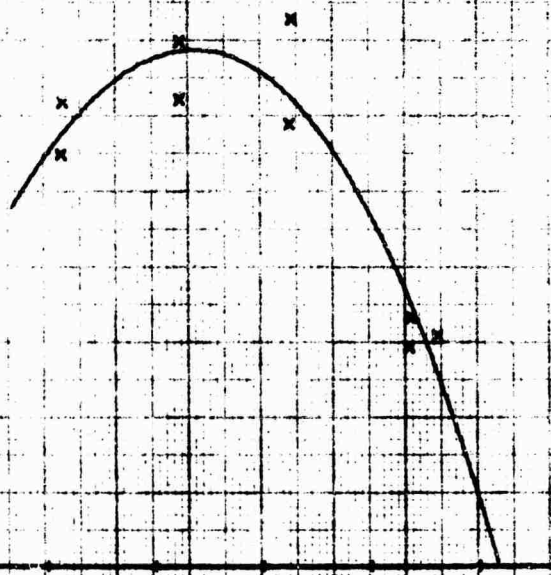
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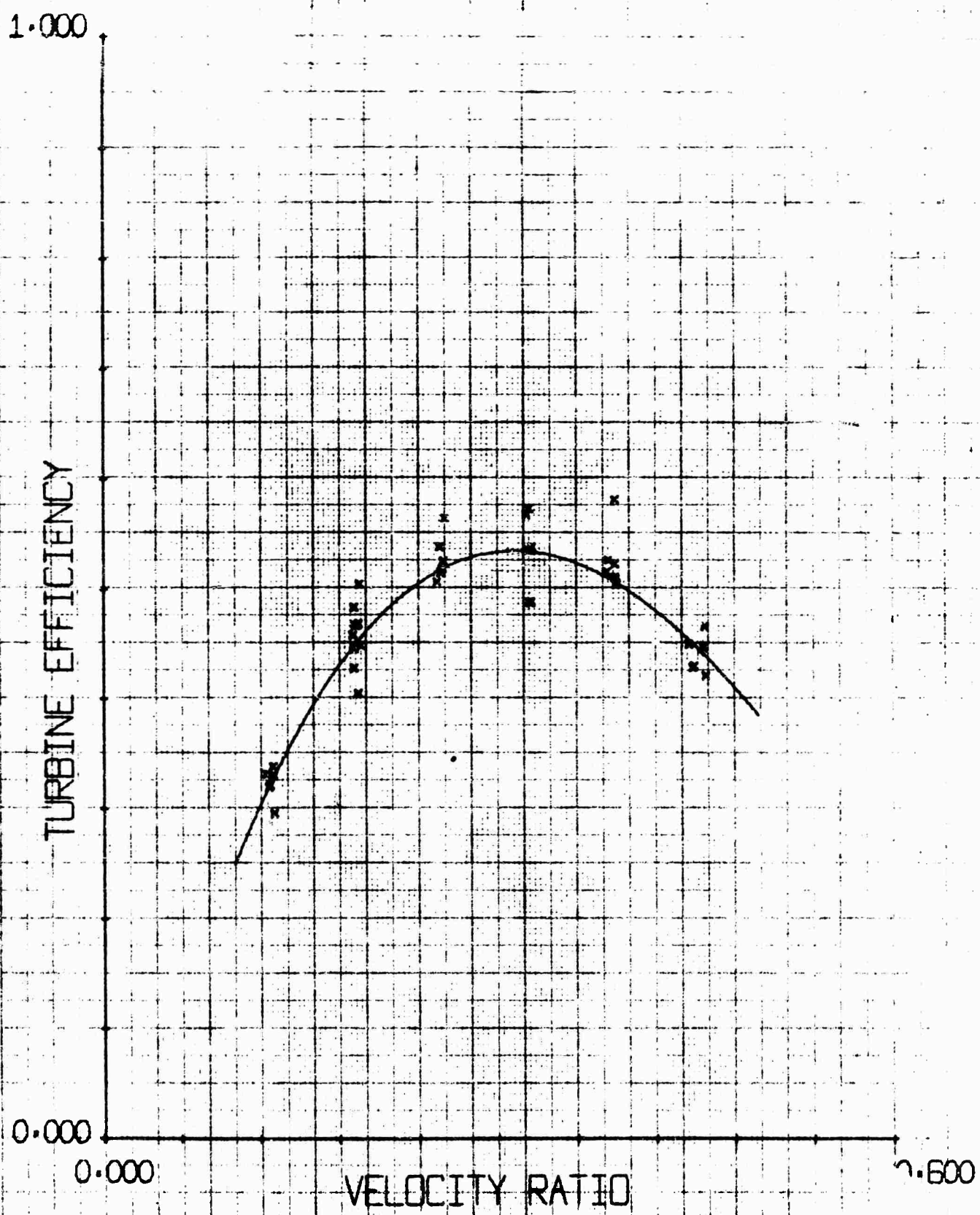
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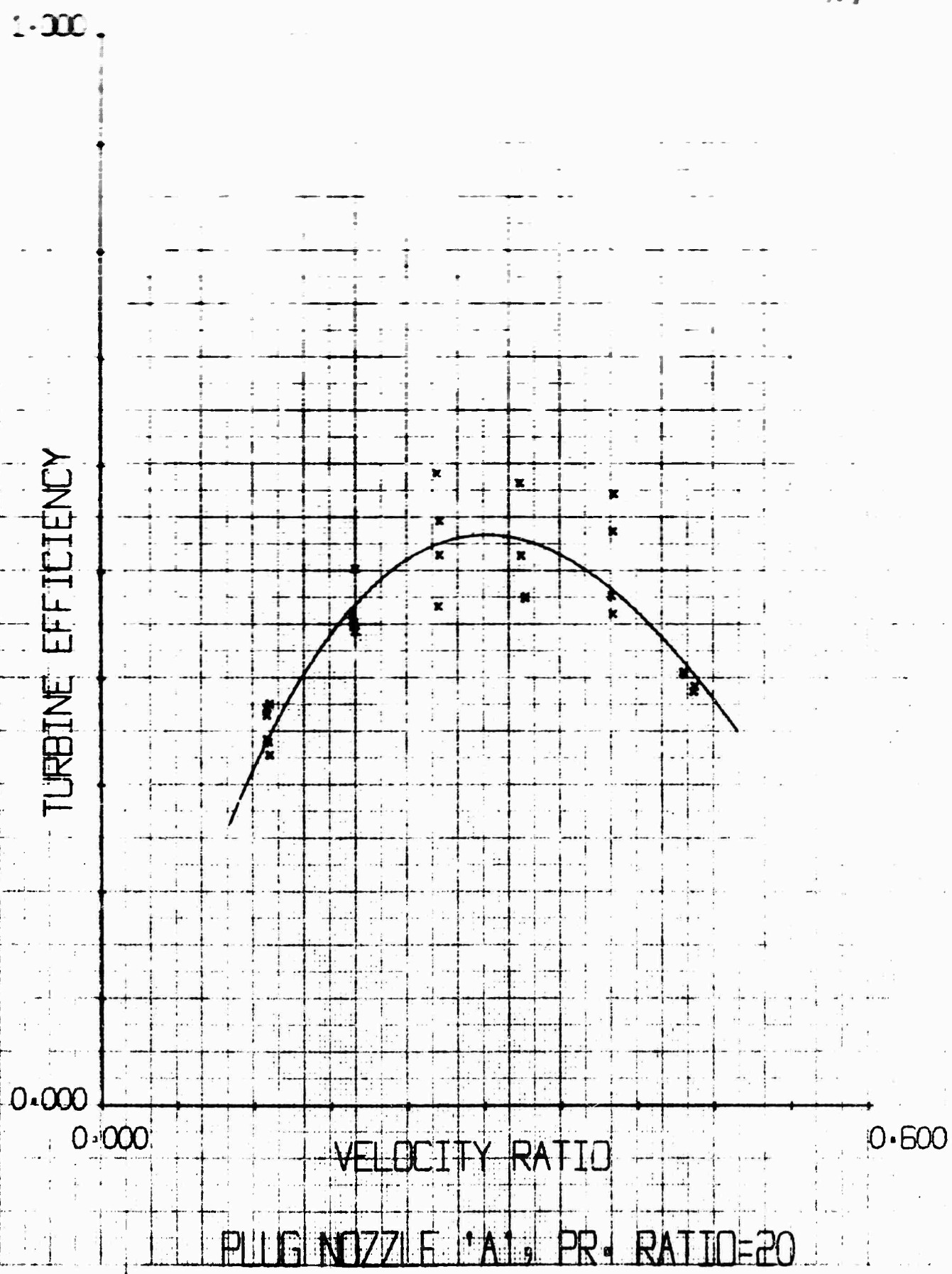
MACH 4.0, PR. RATIO=25, HALF ANGLE=7



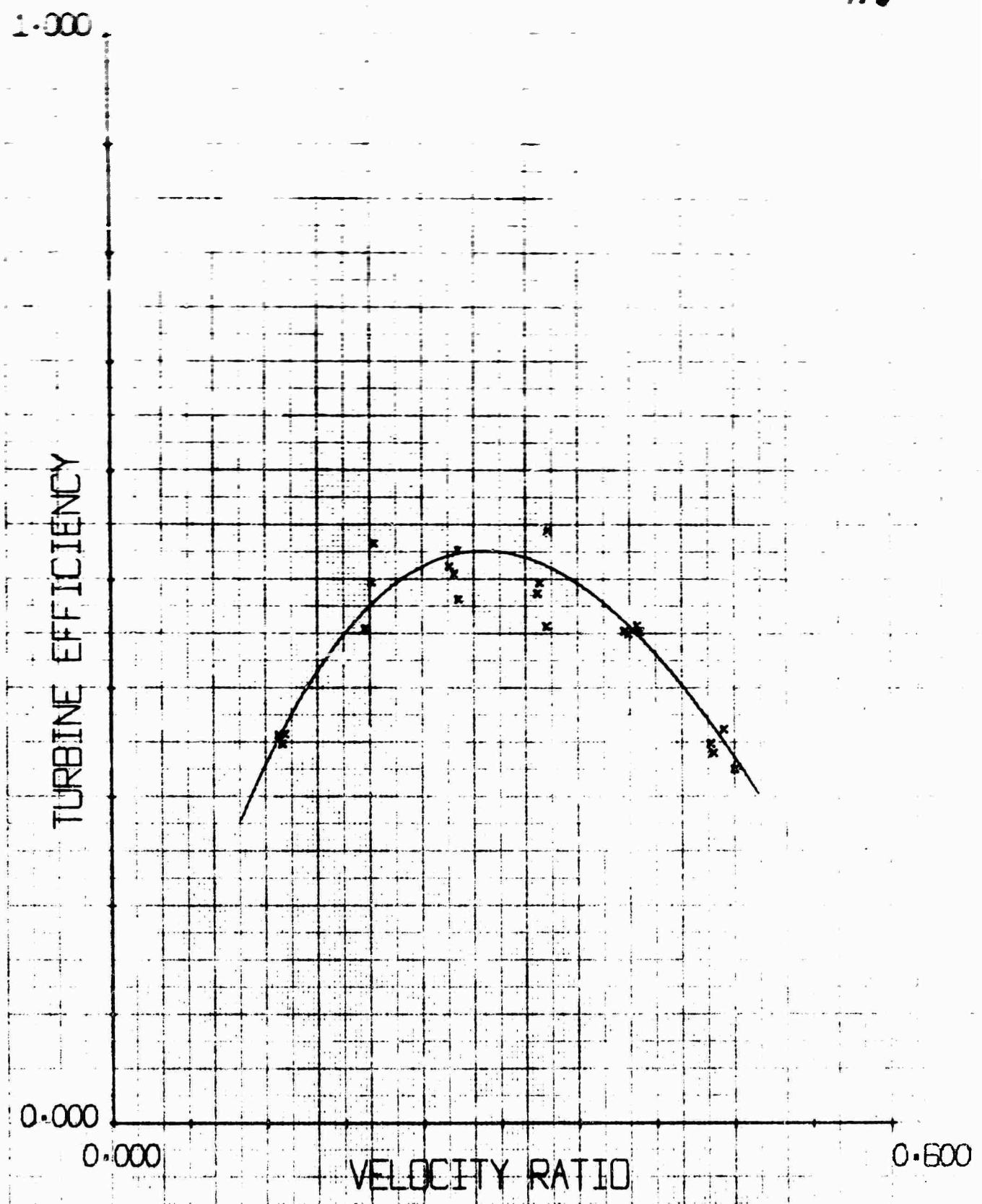




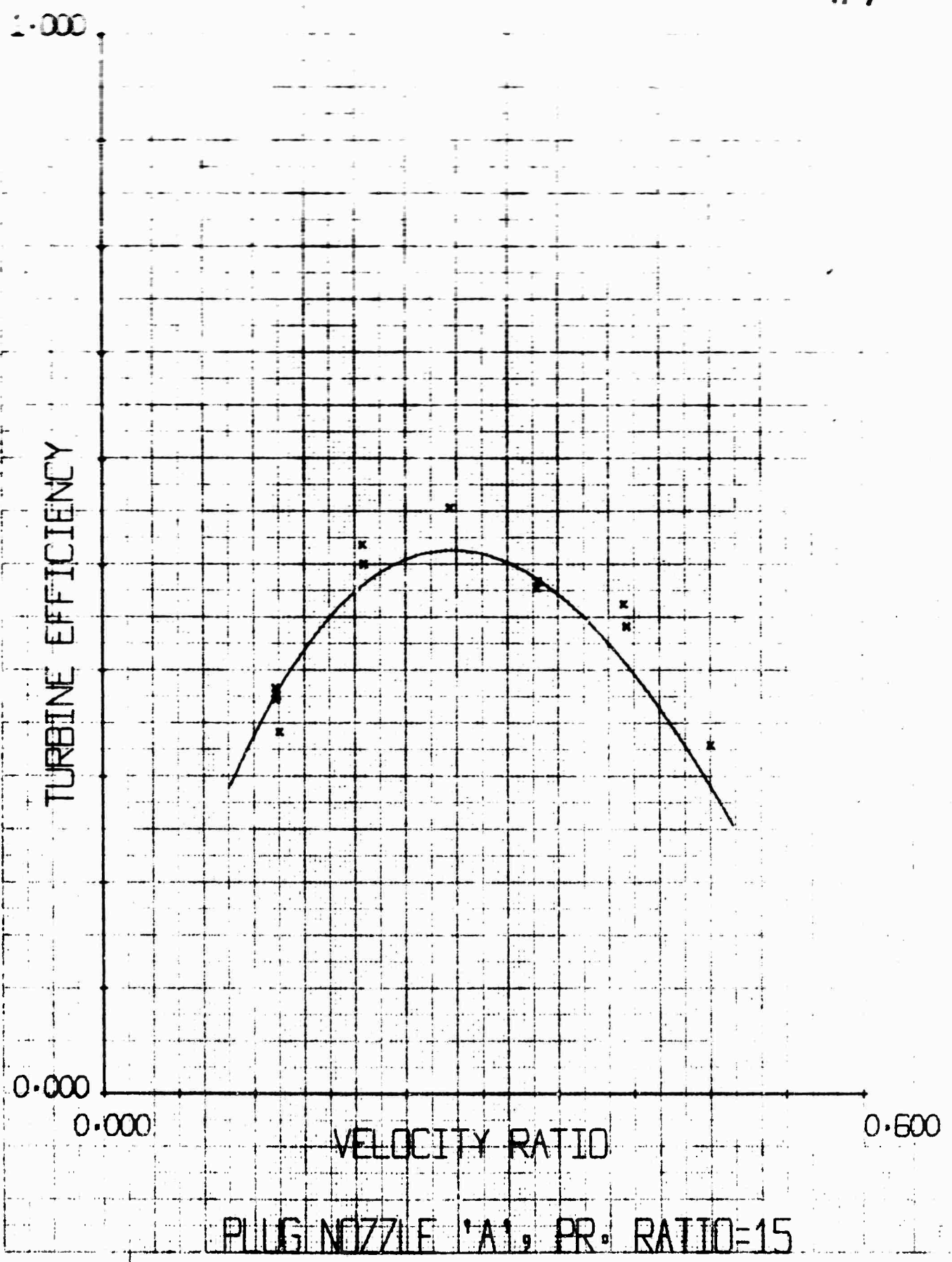
PLUG NOZZLE 'A1', PR. RATIO=25







PLUG NOZZLE 'A', PR. RATIO=17



1.000

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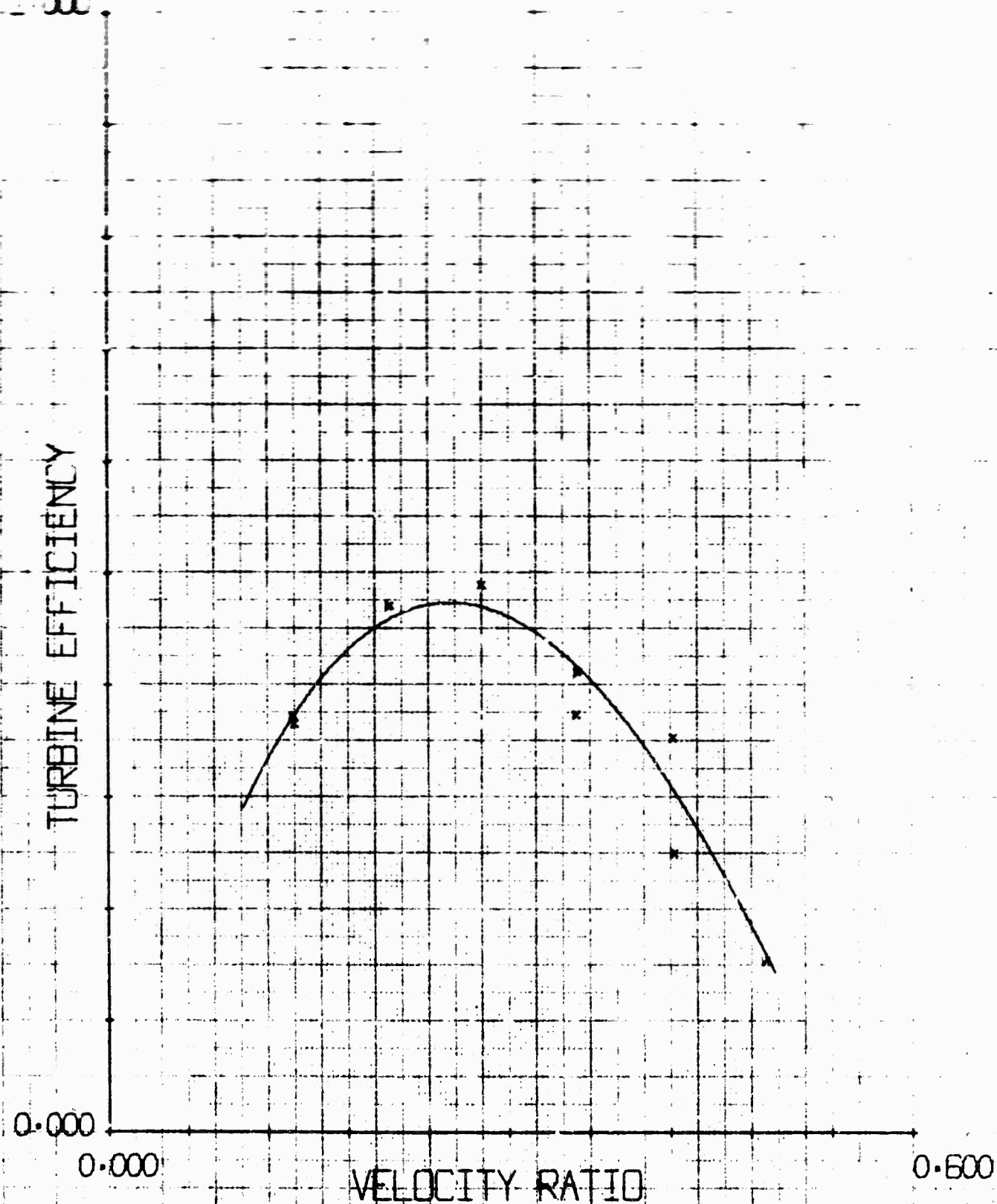
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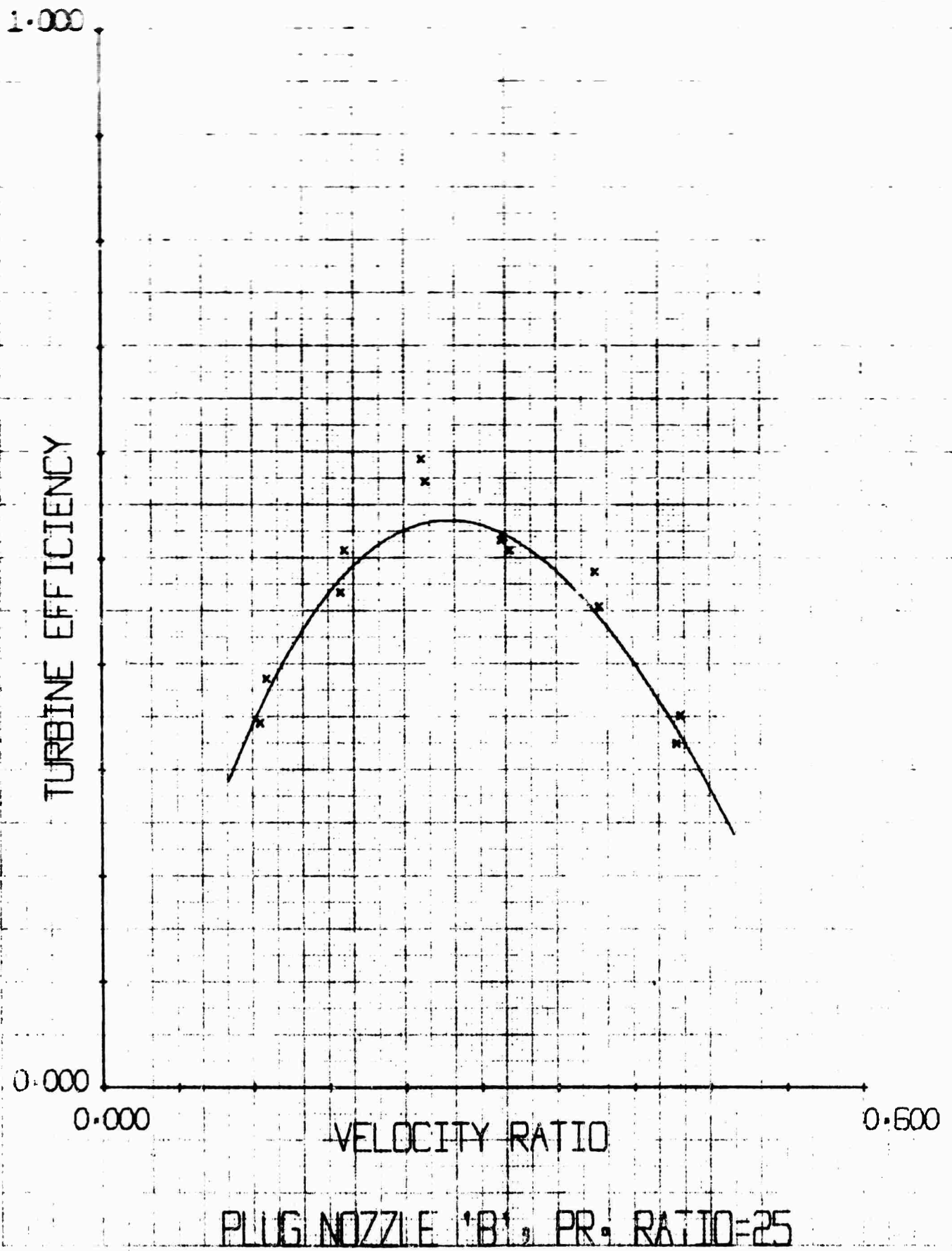
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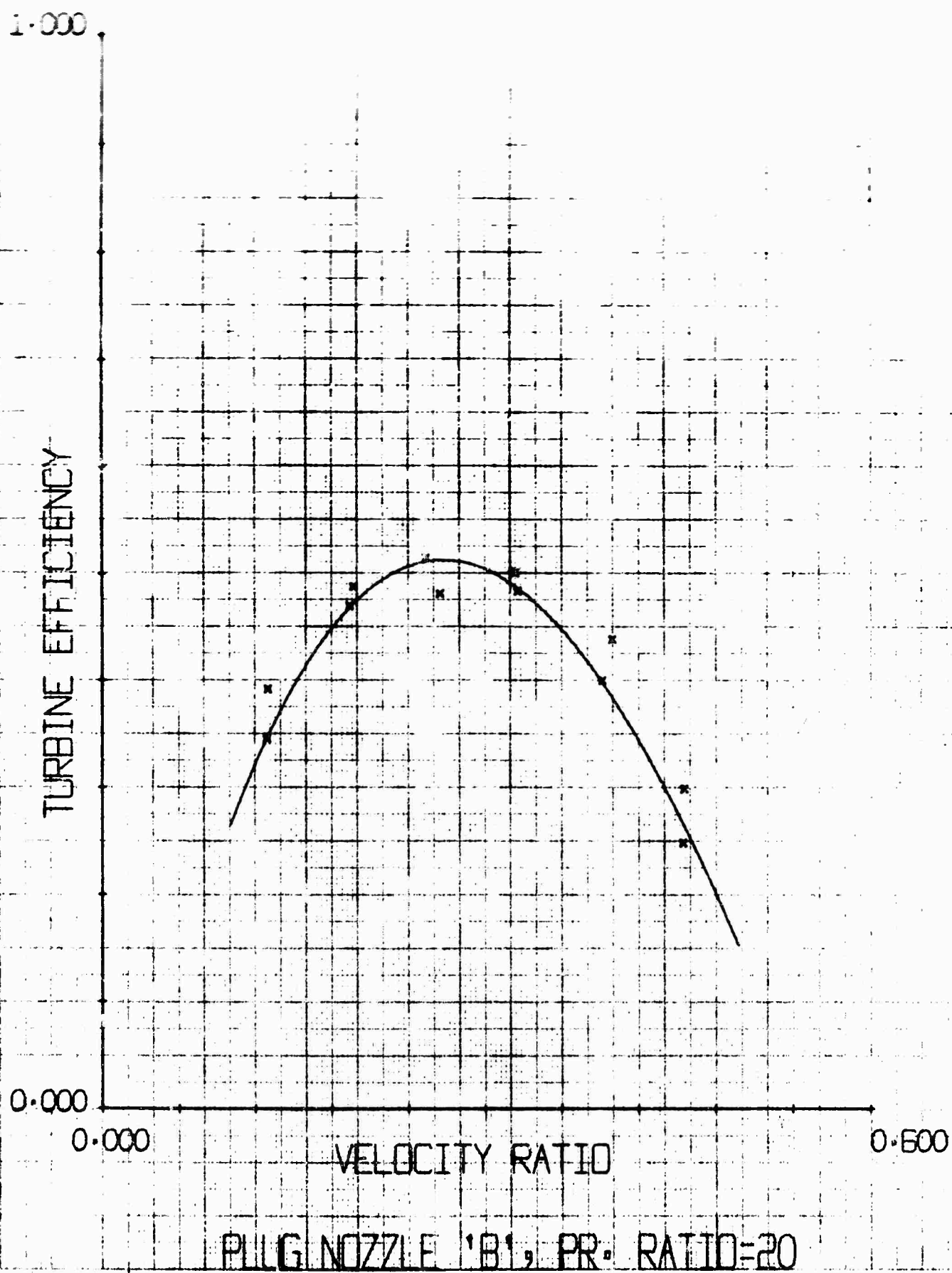
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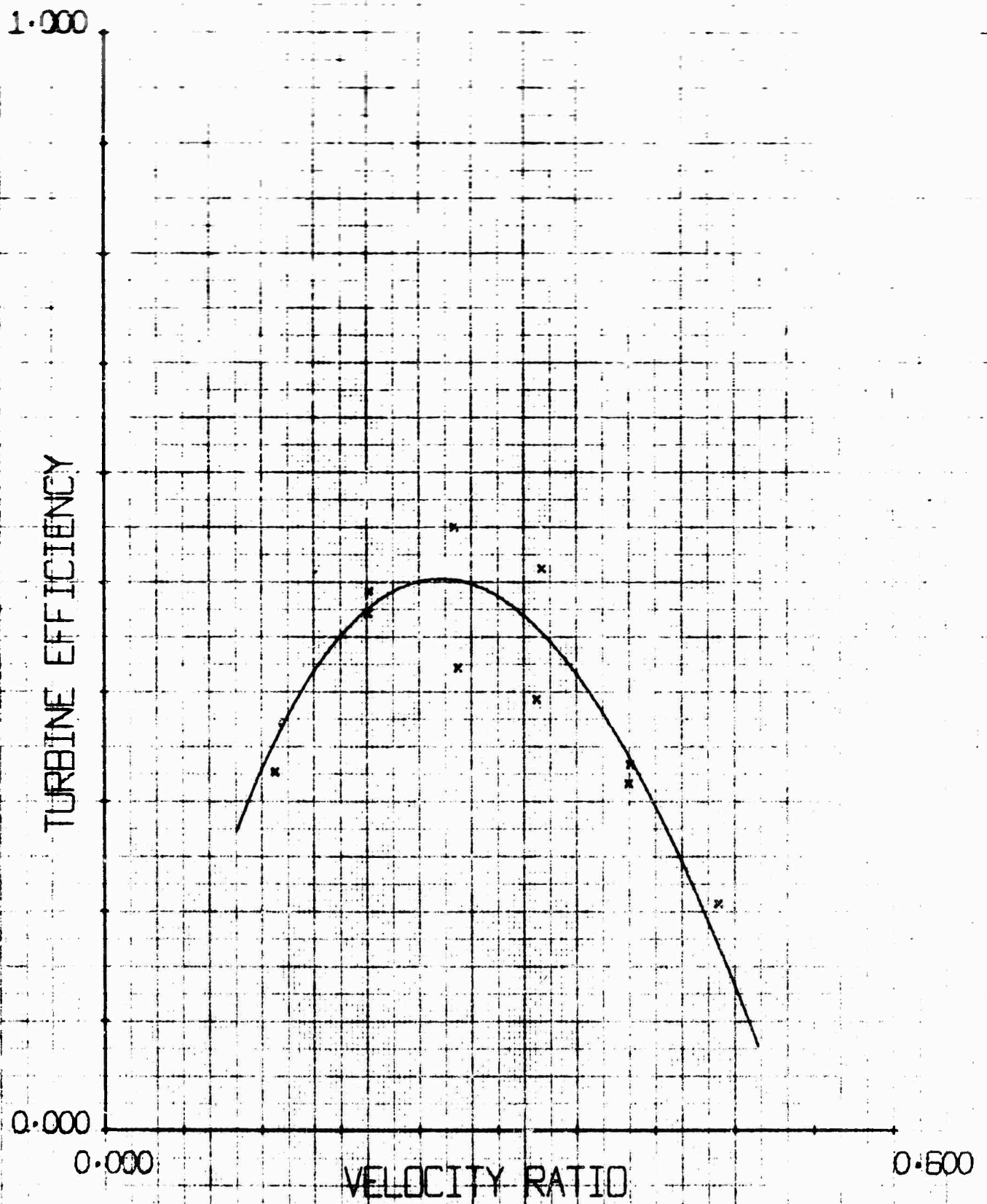
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PLUG NOZZLE 'A', PR. RATIO=12

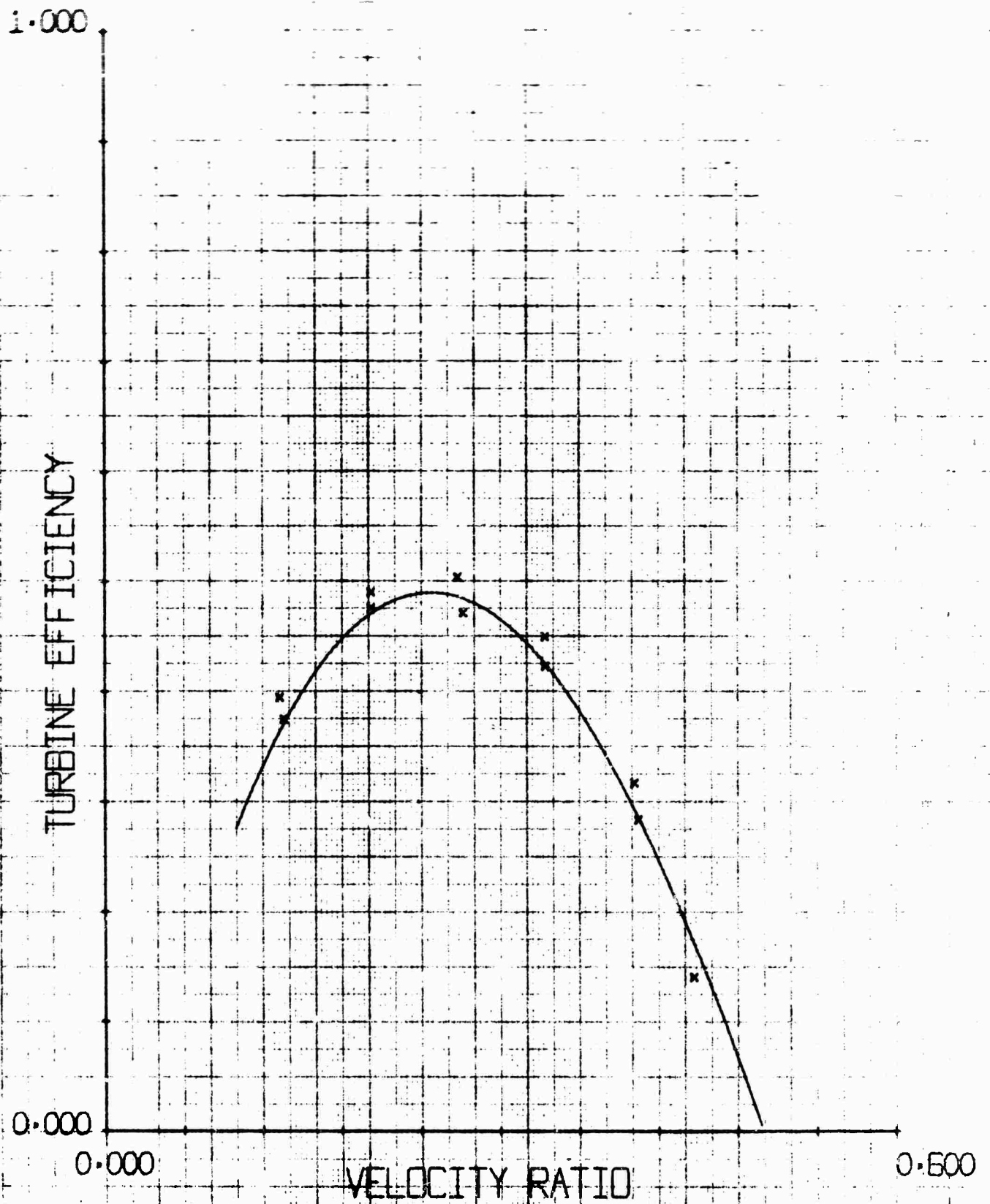






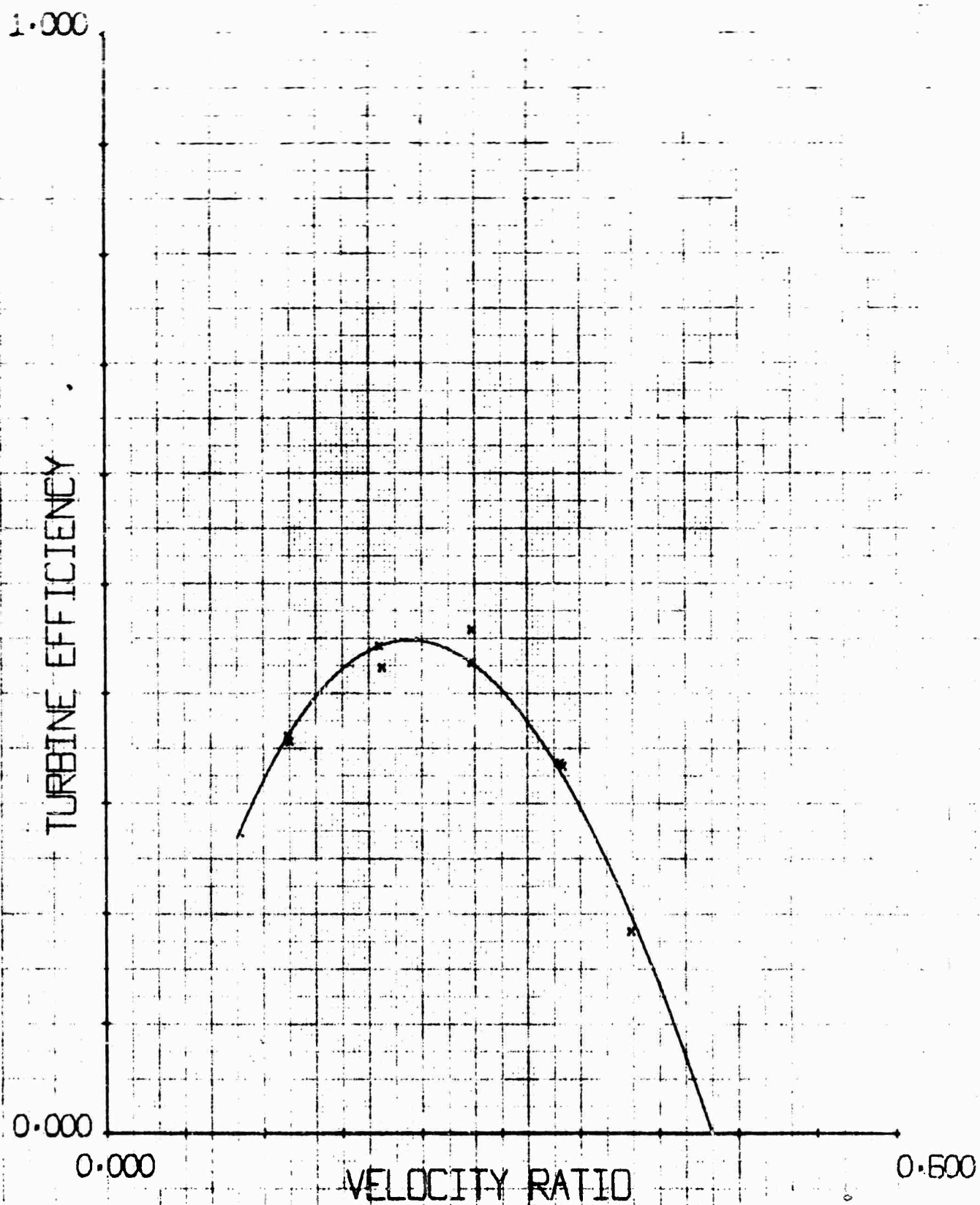


PLUG NOZZLE 'B', PR. RATIO=17



PLUG NOZZLE 'B1', PR. RATIO=15





PLUG NOZZLE 'B', PR. RATIO=12

1.000

TURBINE EFFICIENCY

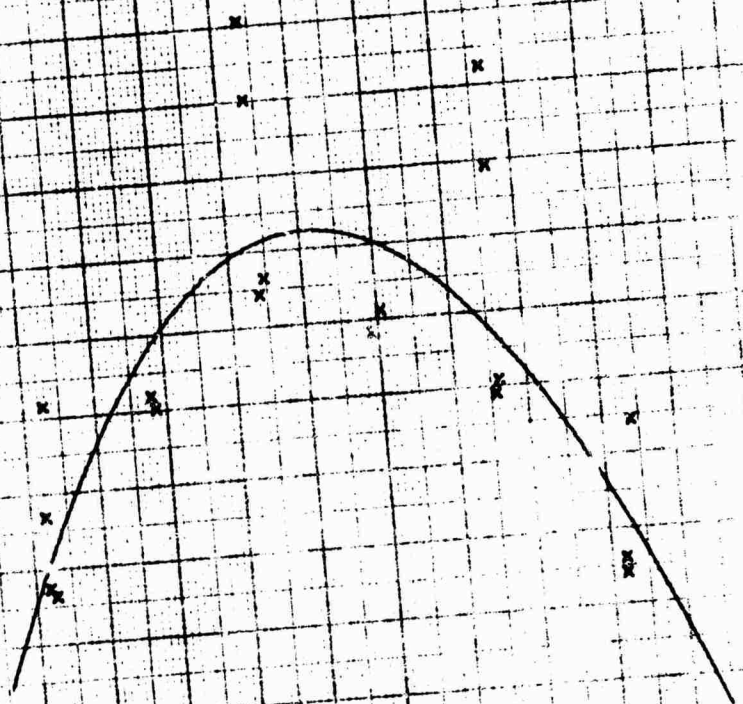
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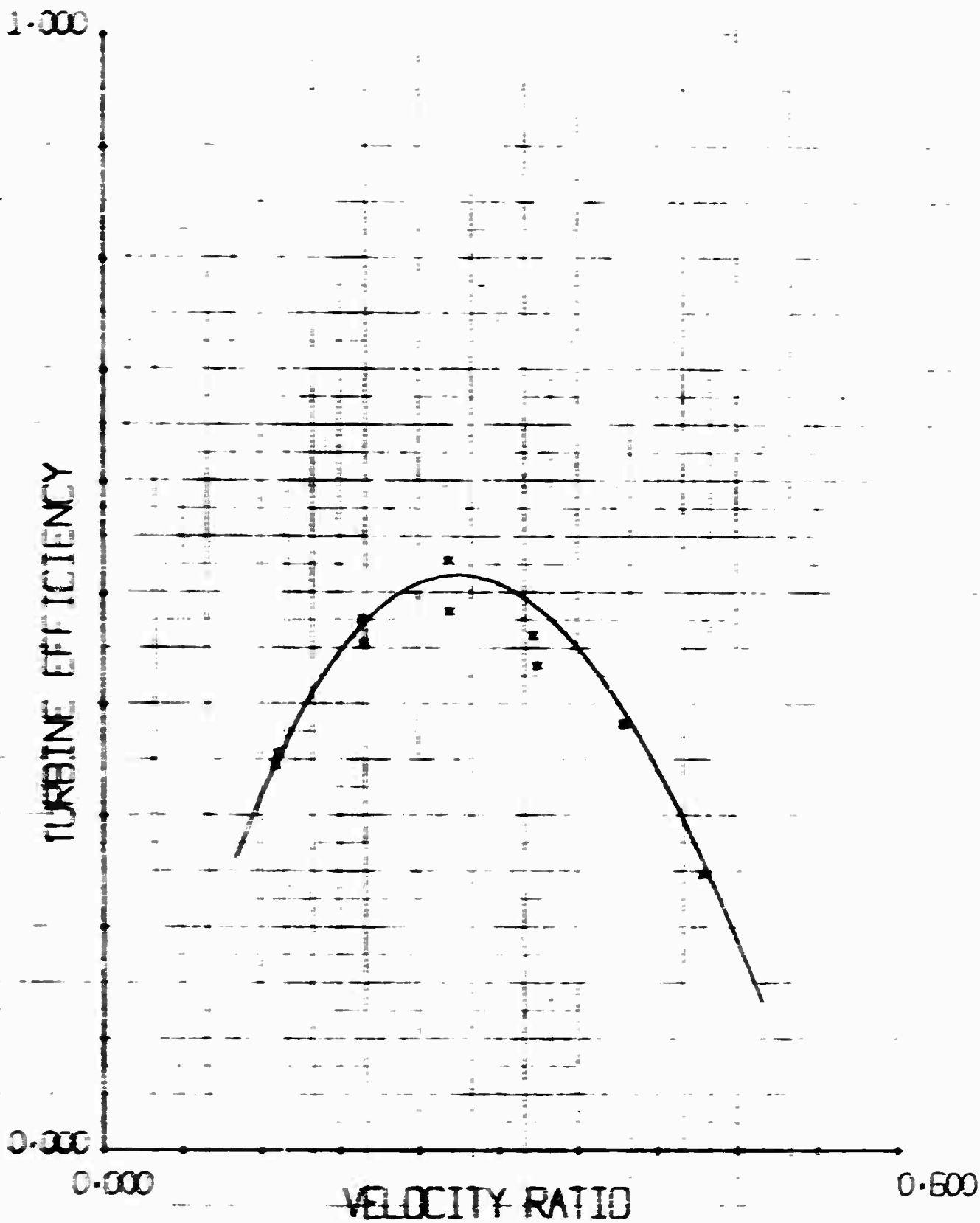
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VELOCITY RATIO

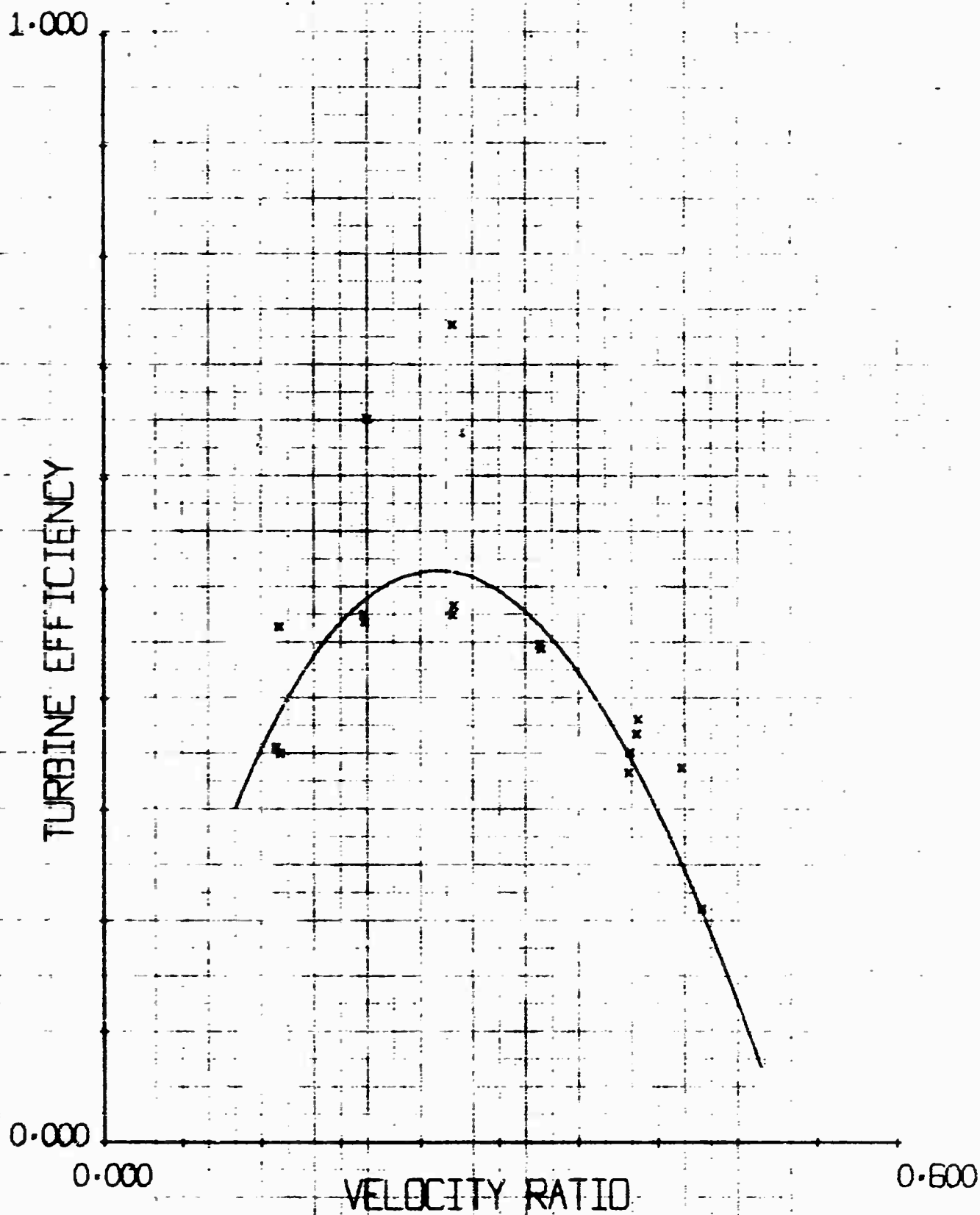
0.600

PLUG NOZZLE 'C1, PR. RATIO=25

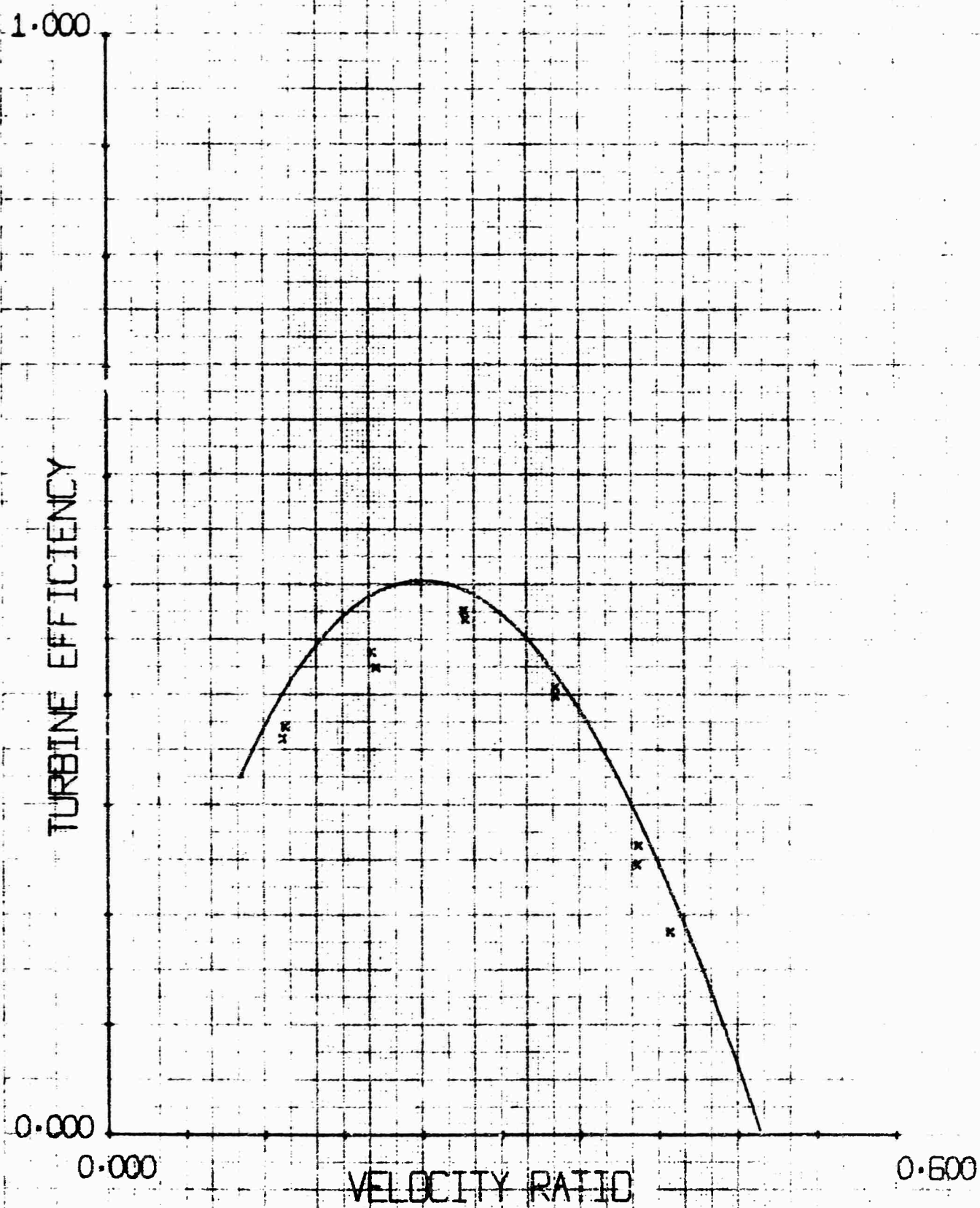




PLUG NOZZLE 'C1, PR. RATIO=20



PLUG NOZZLE 'C', PR. RATIO=17



PLUG NOZZLE 'C', PR. RATIO=15

1.000

TURBINE EFFICIENCY

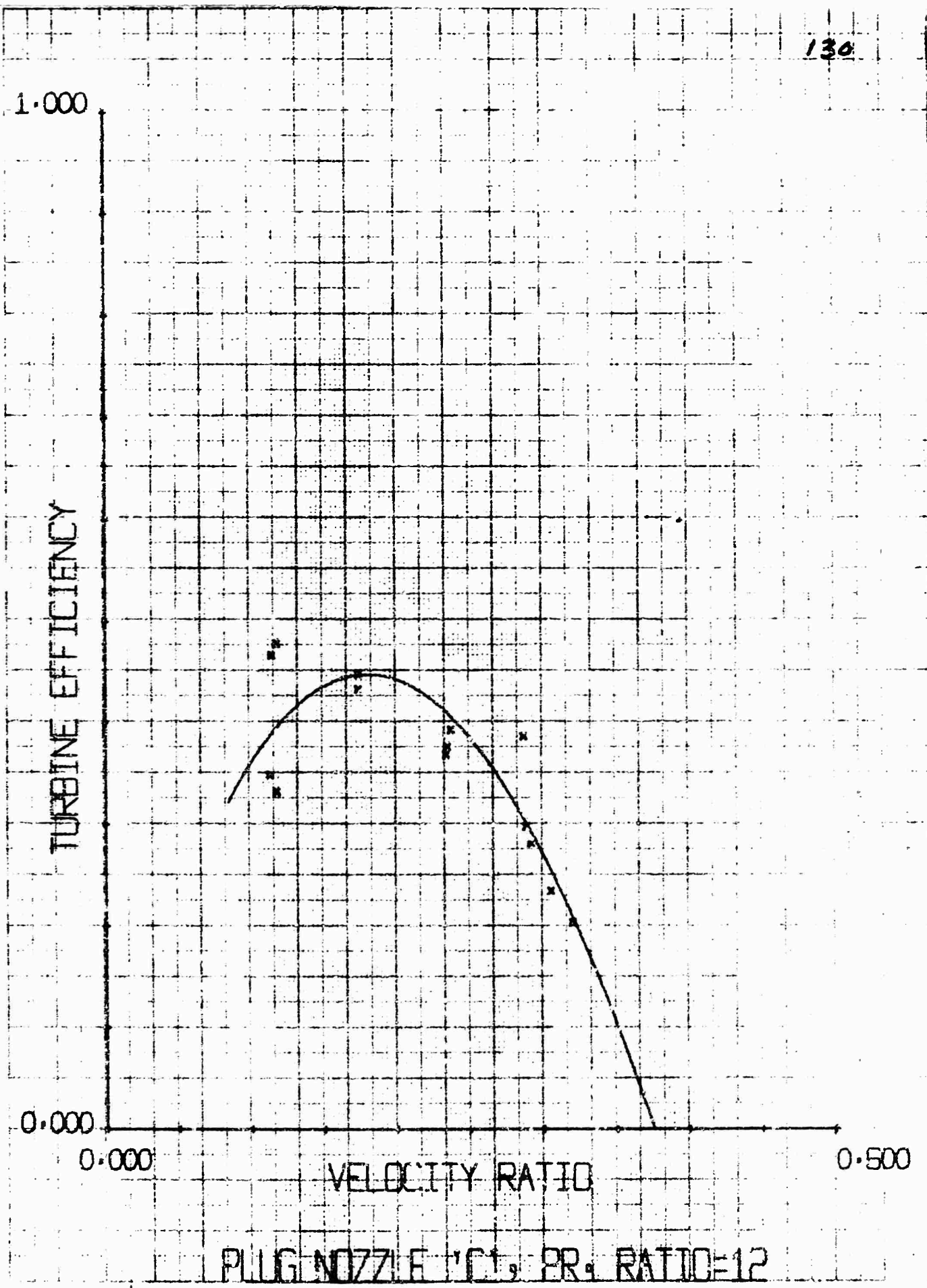
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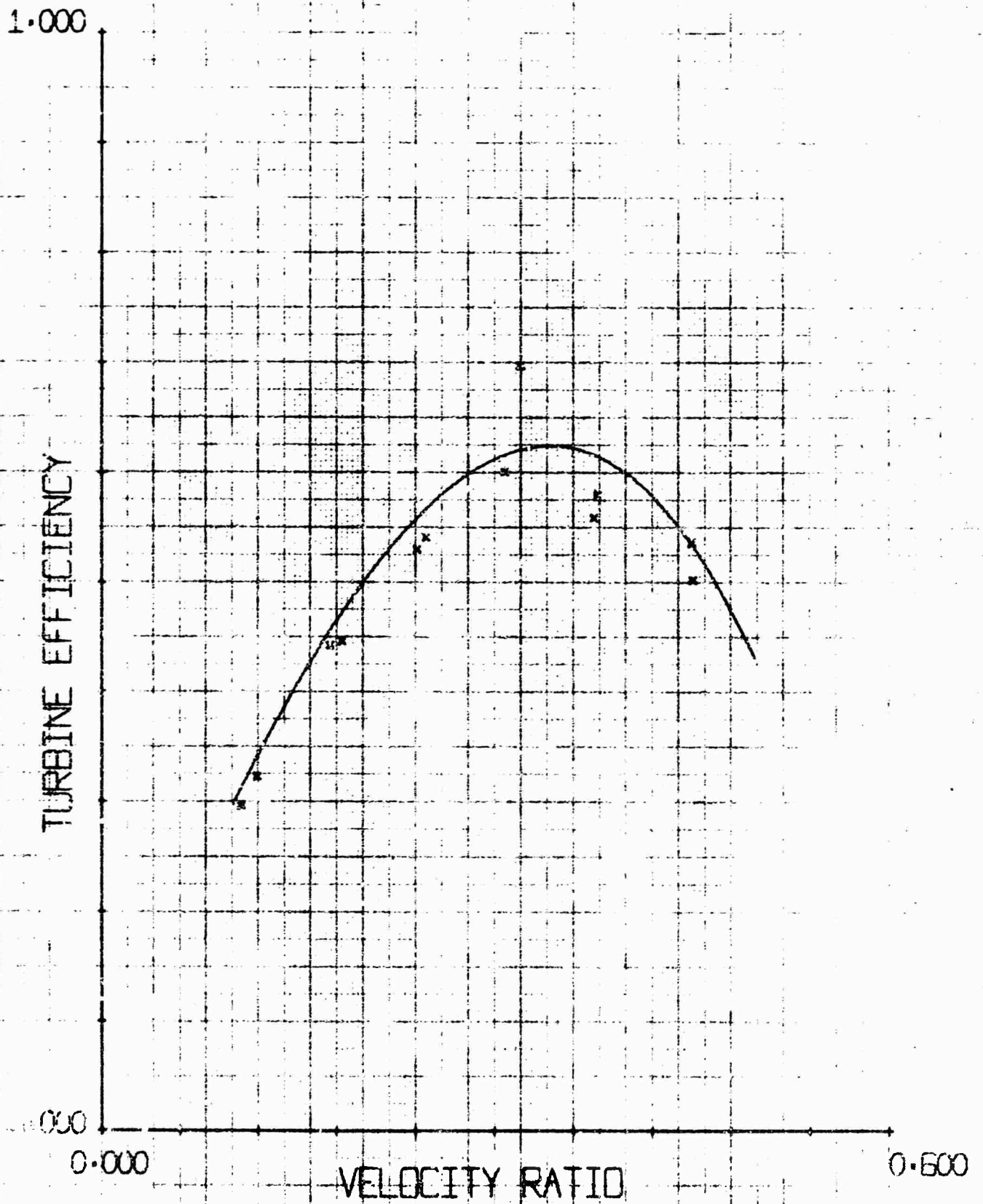
0.000

VELOCITY RATIO

0.500

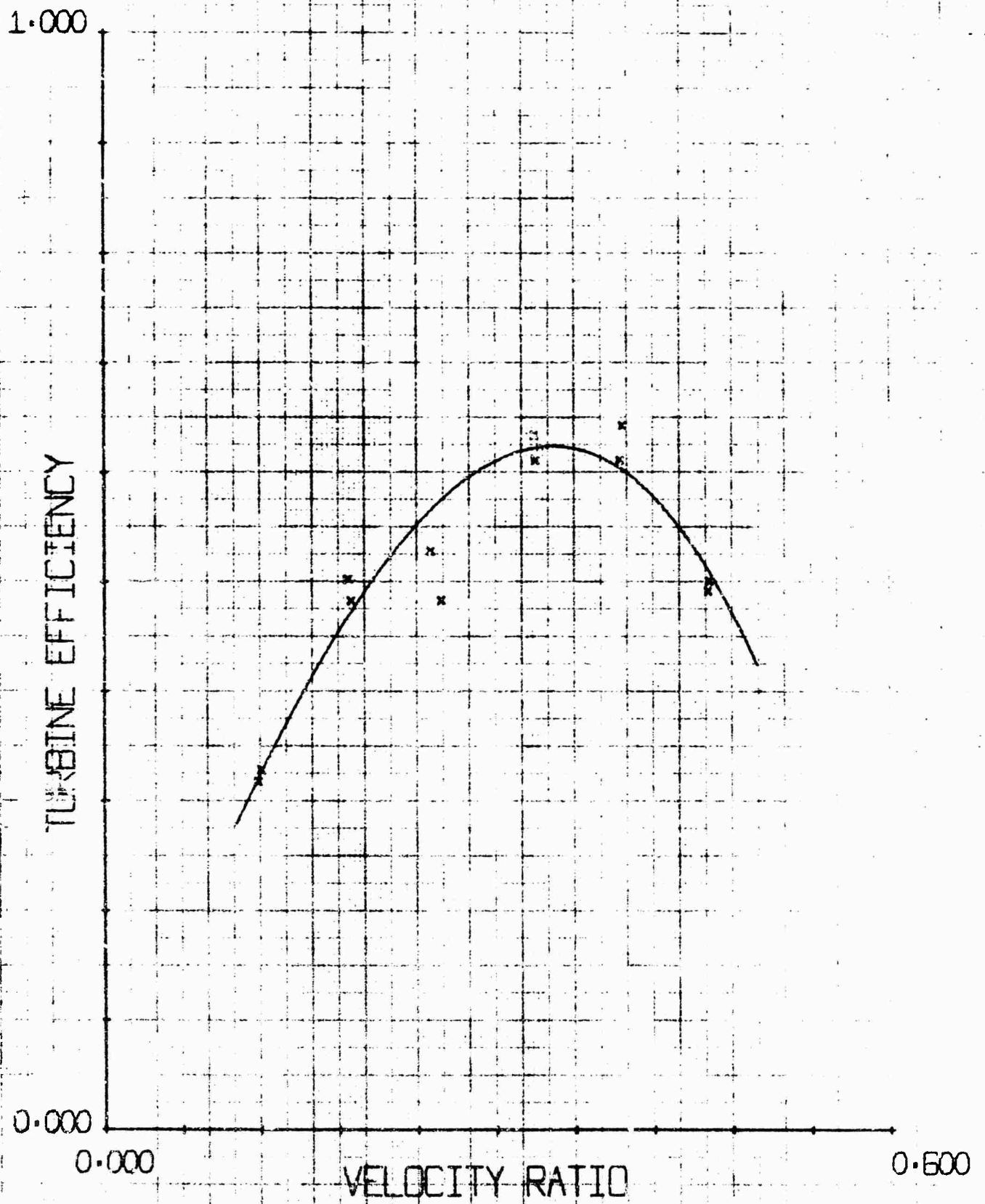
PLUG NOZZLE FLOW, PR. RATIO=12



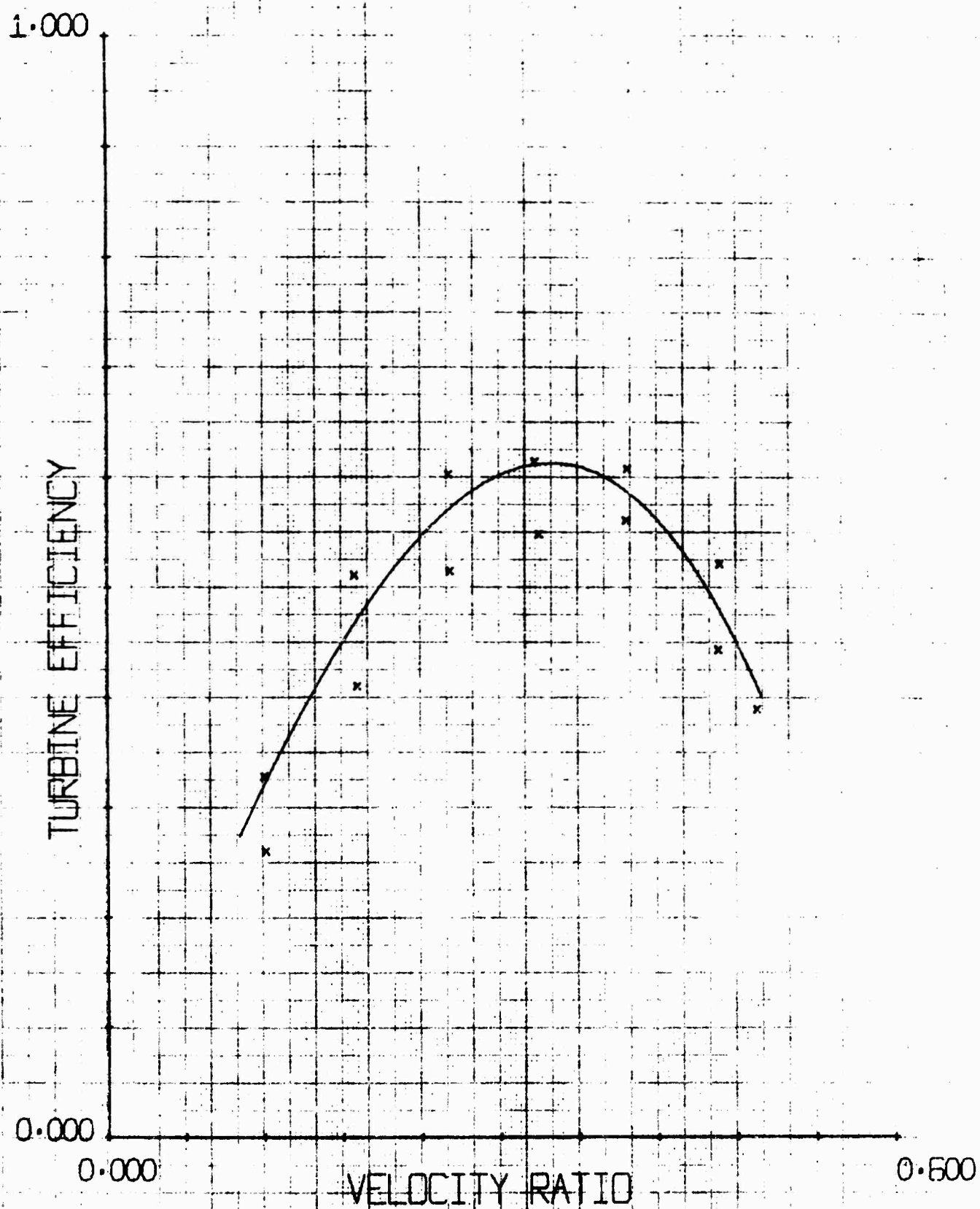


ARGON, PR. RATIO=35, HALF ANGLE =11





ARGON, PR. RATIO=28, HALF ANGLE =11



ARGON; PR: RATIO=25; HALF ANGLE =11

1.000

TURBINE EFFICIENCY

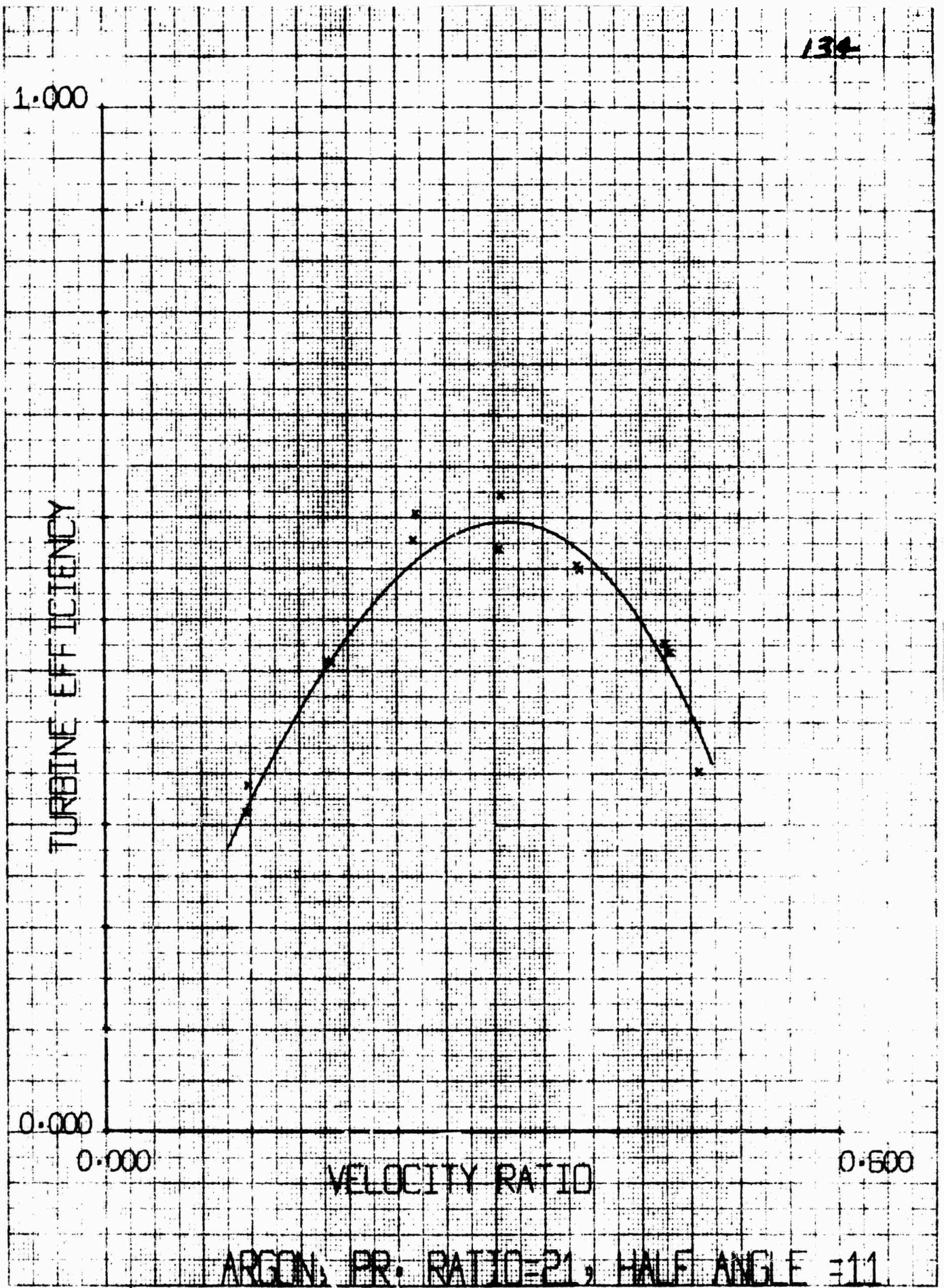
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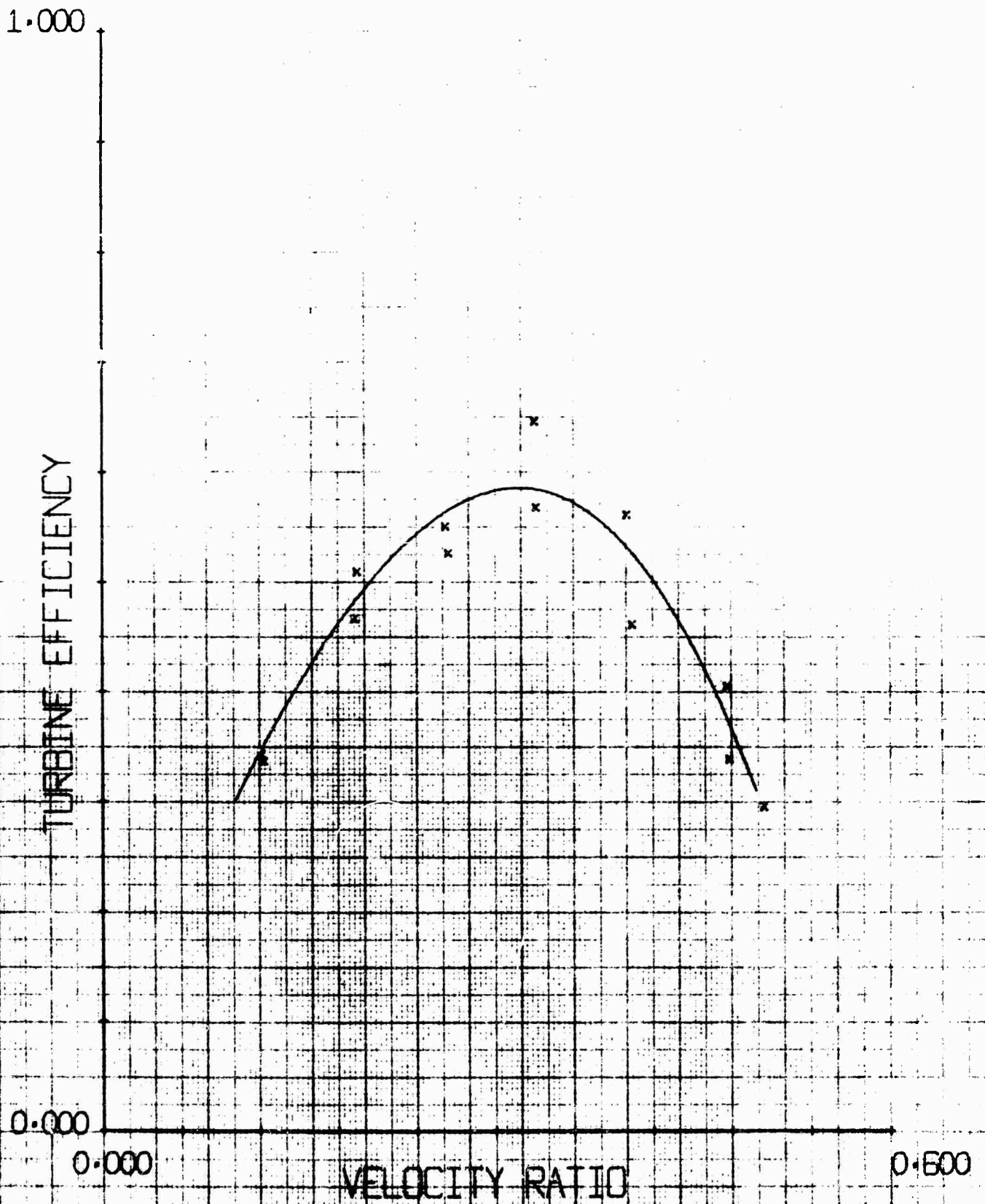
0.000

VELOCITY RATIO

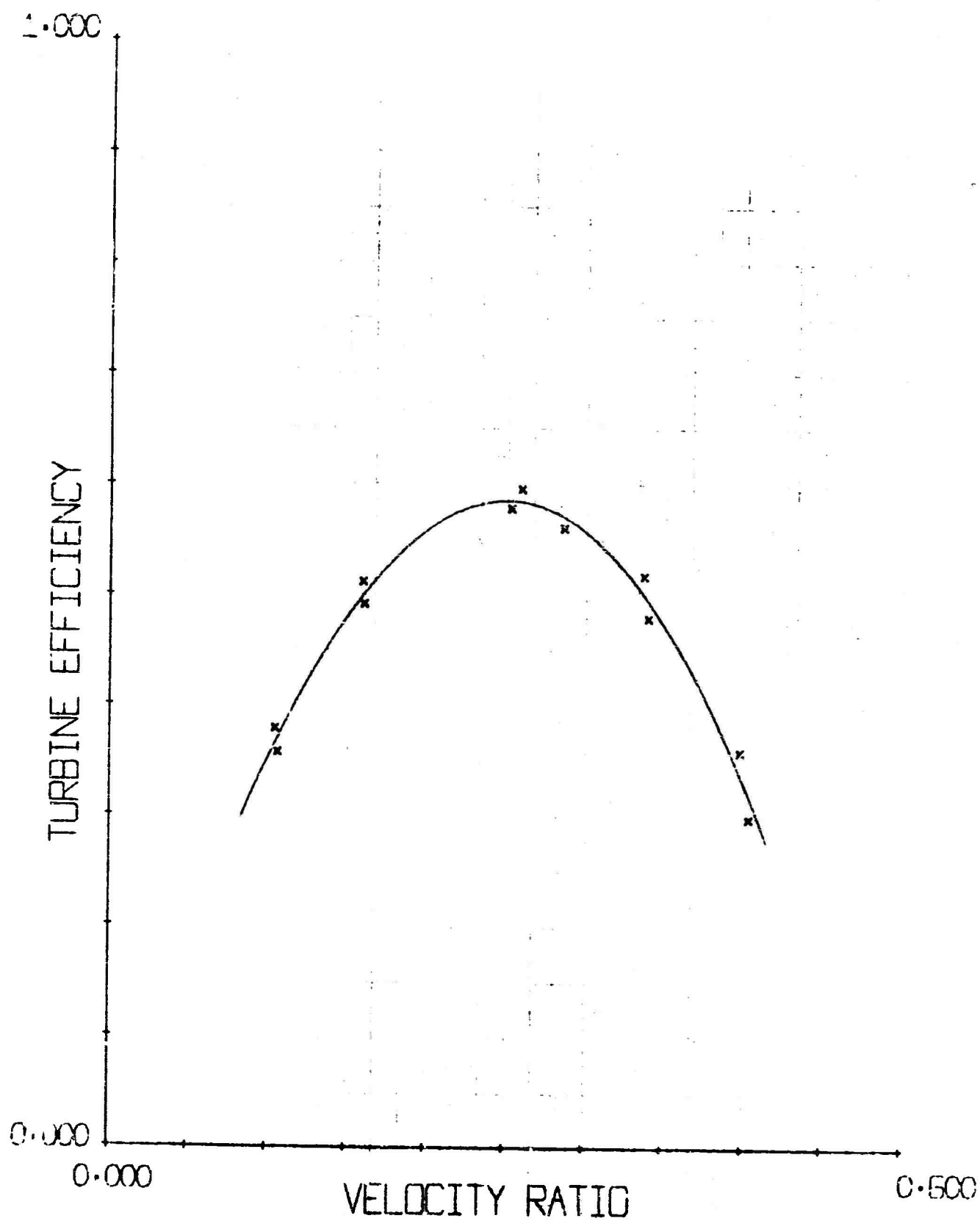
0.600

ARGON; PR. RATIO=21, HALF ANGLE =11





ARCON PR. RATIO=17, HALF ANGLE=11



FREON, PR. RATIO=13, HALF ANGLE=11

**SUNDSTRAND AVIATION**

**ATR 2001**

**Rockford, Illinois**

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**APPENDIX B**

**LIST OF DATA POINTS**

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.190000	0.464000	0.090819
24.660003		0.463091	0.195731
2.515	0.256000	0.519000	1.207018
24.660003		0.531070	2.325661
2.515	0.322000	0.563000	1.095366
24.660003		0.552046	1.945589
2.515	0.391000	0.504000	2.280843
24.660003		0.526808	4.525483
2.515	0.440000	0.492000	1.063806
24.660003		0.481361	2.162207
2.515	0.196000	0.496000	2.471137
23.680000		0.471288	4.982131
2.515	0.262000	0.538000	0.312376
23.680000		0.534876	0.580624
2.515	0.326000	0.549000	0.287044
23.680000		0.551870	0.522849
2.515	0.396000	0.548000	2.480865
23.560001		0.523191	4.527125
2.515	0.439000	0.476000	0.650864
23.560001		0.482508	1.367363

THE NUMBER OF DATA POINTS IS 10

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.194

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.313



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.204000	0.461000	1.116198
19.470001		0.449838	2.421255
2.515	0.271000	0.519000	0.609932
19.630001		0.525099	1.175302
2.515	0.332000	0.565000	2.113438
19.310001		0.543865	3.740598
2.515	0.404000	0.516000	0.560343
19.240001		0.510396	1.085936
2.515	0.440000	0.460000	1.293379
19.180000		0.472933	2.811694

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.138

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.246

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.192000	0.471000	0.381523
16.910003		0.467184	0.810028
2.515	0.263000	0.534000	0.248885
16.910003		0.536488	0.466077
2.515	0.331000	0.531000	0.164985
16.810001		0.529350	0.310707
2.515	0.394000	0.502000	2.049082
16.910003		0.481509	4.081837
2.515	0.450000	0.414000	0.885683
16.910003		0.422856	2.139331

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.746

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.561

## O.M.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL,
2.515 ----- 14.800001	0.203000 -----	0.516000 ----- 0.463226	5.277378 ----- 10.227478
2.515 ----- 14.800001	0.270000 -----	0.521000 ----- 0.522687	0.168738 ----- 0.323970
2.515 ----- 14.920000	0.335000 -----	0.453000 ----- 0.517195	6.419540 ----- 14.171171
2.515 ----- 15.030000	0.405000 -----	0.450000 ----- 0.445894	0.410604 ----- 0.912454
2.515 ----- 14.800001	0.444000 -----	0.406000 ----- 0.378381	2.761865 ----- 6.802623

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.007

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 6.487

# J.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL,
2.515 ----- 11.820001	0.207000 -----	0.472000 ----- 0.445499	2.650094 ----- 5.614606
2.515 ----- 11.820001	0.276000 -----	0.479000 ----- 0.516038	3.703821 ----- 7.732402
2.515 ----- 11.920001	0.346000 -----	0.449000 ----- 0.481361	3.238106 ----- 7.211818
2.515 ----- 11.820001	0.415000 -----	0.362000 ----- 0.361551	0.044900 ----- 0.124033

THE NUMBER OF DATA POINTS IS 4  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.409  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.170

## D.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.513	0.124000	0.359000	0.998467
24.730003		0.366984	2.701246
2.513	0.153000	0.423000	1.256388
24.730003		0.425543	2.970185
2.513	0.189000	0.489000	1.560145
24.730003		0.503601	3.197020
2.513	0.219000	0.541000	0.724554
24.730003		0.546245	1.339287
2.513	0.251000	0.568000	1.610732
24.730003		0.584107	2.835796
2.513	0.288000	0.596000	1.485979
24.730003		0.610859	2.493254
2.513	0.319000	0.624000	0.252664
24.730003		0.621473	0.404910
2.513	0.348000	0.610000	1.193952
24.730003		0.621939	1.957299
2.513	0.384000	0.606000	0.416278
24.730003		0.610162	0.586928
2.513	0.418000	0.559000	2.786291
24.730003		0.536862	4.984420

THE NUMBER OF DATA POINTS IS 10

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.228

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.365

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT SMOOTHED DATA POINT	SCATTER PER CENT EFF. SCATTER PER CENT VAL.
2.513 19.780002	0.129000	0.378000 0.382604	0.460422 1.218047
2.513 19.780002	0.161000	0.442000 0.458203	1.620376 3.666009
2.513 19.780002	0.196000	0.515000 0.523959	0.895905 1.739622
2.513 19.780002	0.231000	0.593000 0.572729	2.027011 3.418231
2.513 19.780002	0.262000	0.589000 0.602326	1.332517 2.262507
2.513 19.780002	0.293000	0.586000 0.619672	3.367209 3.746091
2.513 19.780002	0.331000	0.644000 0.624962	1.903784 2.956187
2.513 19.780002	0.363000	0.588000 0.616409	2.840948 4.831545
2.513 19.780002	0.395000	0.573000 0.596554	2.355421 4.110682
2.513 19.780002	0.431000	0.582000 0.561396	2.060306 3.540045
2.513 19.780002	0.465000	0.511000 0.516414	0.541424 1.059540

THE NUMBER OF DATA POINTS IS 11  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.764  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.140

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.513	0.136000	0.432000	2.987462
-----	-----	-----	-----
16.490001		0.402125	6.915422
2.513	0.171000	0.462000	3.510731
-----	-----	-----	-----
16.490001		0.497107	7.598986
2.513	0.200000	0.541000	1.275992
-----	-----	-----	-----
16.490001		0.553759	2.358582
2.513	0.234000	0.566000	3.162575
-----	-----	-----	-----
16.490001		0.597625	5.587588
2.513	0.269000	0.656000	3.538561
-----	-----	-----	-----
16.490001		0.620614	5.394148
2.513	0.304000	0.636000	1.137769
-----	-----	-----	-----
16.490001		0.624622	1.788945
2.513	0.337000	0.612000	0.220036
-----	-----	-----	-----
16.490001		0.614200	0.359536
2.513	0.371000	0.587000	0.524652
-----	-----	-----	-----
16.490001		0.592246	0.893785
2.513	0.405000	0.531000	3.112650
-----	-----	-----	-----
16.490001		0.562126	5.861866
2.513	0.438000	0.514000	1.415682
-----	-----	-----	-----
16.490001		0.528156	2.754245

THE NUMBER OF DATA POINTS IS 10

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.088

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.951



O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.513	0.132000	0.404000	2.205318
-----	-----	-----	-----
14.960001		0.426053	5.458708
2.513	0.170000	0.493000	1.667517
-----	-----	-----	-----
14.960001		0.509675	3.382388
2.513	0.203000	0.536000	2.881014
-----	-----	-----	-----
14.840000		0.564810	5.375028
2.513	0.240000	0.612000	0.408184
-----	-----	-----	-----
14.840000		0.607918	0.666968
2.513	0.260000	0.619000	0.421035
-----	-----	-----	-----
14.960001		0.623210	0.680186
2.513	0.273000	0.650000	1.979816
-----	-----	-----	-----
14.960001		0.630201	3.045871
2.513	0.307000	0.636000	0.174152
-----	-----	-----	-----
14.960001		0.637741	0.273825
2.513	0.339000	0.625000	0.600087
-----	-----	-----	-----
14.960001		0.631000	0.960140
2.513	0.377000	0.596000	1.017964
-----	-----	-----	-----
14.960001		0.606179	1.707993
2.513	0.406000	0.571000	0.437700
-----	-----	-----	-----
14.960001		0.575377	0.766551
2.513	0.449000	0.506000	0.555145
-----	-----	-----	-----
14.960001		0.511551	1.097126

THE NUMBER OF DATA POINTS IS 11  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.122  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.128

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
2.513 ----- 11.970001	0.138000 -----	0.405000 ----- 0.394147	1.085239 ----- 2.679604
2.513 ----- 11.970001	0.172000 -----	0.487000 ----- 0.491073	0.407379 ----- 0.836508
2.513 ----- 12.070001	0.209000 -----	0.568000 ----- 0.563251	0.474858 ----- 0.836018
2.513 ----- 12.070001	0.249000 -----	0.594000 ----- 0.605506	1.150679 ----- 1.937171
2.513 ----- 12.070001	0.278000 -----	0.643000 ----- 0.614919	2.808022 ----- 4.367065
2.513 ----- 12.070001	0.317000 -----	0.627000 ----- 0.602187	2.481270 ----- 3.957368
2.513 ----- 12.070001	0.351000 -----	0.569000 ----- 0.569738	0.073862 ----- 0.129810
2.513 ----- 12.070001	0.386000 -----	0.556000 ----- 0.516048	3.795147 ----- 6.825804
2.513 ----- 12.070001	0.428000 -----	0.501000 ----- 0.434959	6.604076 ----- 13.181789
2.513 ----- 12.070001	0.462000 -----	0.362000 ----- 0.353602	0.839769 ----- 2.319806

THE NUMBER OF DATA POINTS IS 10  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.972  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.707

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.511	0.127000	0.370000	0.371420
25.000003		0.366285	1.003839
2.511	0.188000	0.541000	3.841484
25.000003		0.502585	7.100710
2.511	0.157000	0.453000	1.355666
25.000003		0.439443	2.992640
2.511	0.222000	0.583000	2.537203
25.080001		0.557628	4.351978
2.511	0.255000	0.584000	1.319372
24.870002		0.597193	2.259200
2.511	0.281000	0.632000	1.301360
25.210002		0.618986	2.059114
2.511	0.317000	0.660000	2.413666
23.250003		0.635863	3.657070
2.511	0.353000	0.598000	3.971648
22.730003		0.637715	6.641553
2.511	0.288000	0.634000	1.053345
24.680000		0.623466	1.661427
2.511	0.322000	0.639000	0.199115
24.580001		0.637008	0.311604
2.511	0.358000	0.636000	0.081145
24.080001		0.636811	0.127587

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.393000	0.683000	5.488360
23.800003		0.628116	8.035667
2.511	0.418000	0.626000	2.150857
23.600002		0.604491	3.435874

THE NUMBER OF DATA POINTS IS 13  
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.006  
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.356

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.511	0.387000	0.652000	3.877270
22.370002	-----	0.613227	5.946734
2.511	0.424000	0.631000	5.231548
22.200000	-----	0.578684	8.290285
2.511	0.446000	0.574000	2.232778
21.960002	-----	0.551672	3.889858
2.511	0.132000	0.436000	2.201760
19.660003	-----	0.413982	5.049908
2.511	0.165000	0.460000	2.814639
19.730003	-----	0.488146	6.118780
2.511	0.198000	0.554000	0.723362
19.830001	-----	0.546766	1.305707
2.511	0.233000	0.648000	5.536938
19.900001	-----	0.592630	8.544658
2.511	0.264000	0.600000	1.980567
19.830001	-----	0.619805	3.300945
2.511	0.295000	0.628000	0.687360
19.830001	-----	0.634873	1.094523
2.511	0.331000	0.672000	3.415453
19.630001	-----	0.637845	5.082521
2.511	0.394000	0.589000	1.877045
19.630001	-----	0.607770	3.186834

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
2.511	0.432000	0.587000	1.759374
-----	-----	-----	-----
19.630001		0.569406	2.997231
2.511	0.462000	0.504000	2.512324
-----	-----	-----	-----
19.250003		0.529123	4.984770

THE NUMBER OF DATA POINTS IS 13

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.680

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.599

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.511	0.134000	0.363000	2.336226
-----	-----	-----	-----
17.140003		0.386362	6.435890
2.511	0.167000	0.474000	0.721204
-----	-----	-----	-----
17.050003		0.481212	1.521528
2.511	0.201000	0.574000	2.287066
-----	-----	-----	-----
17.050003		0.551129	3.984436
2.511	0.234000	0.668000	7.295239
-----	-----	-----	-----
17.000003		0.595047	10.921016
2.511	0.267000	0.588000	3.037953
-----	-----	-----	-----
17.140003		0.618379	5.166588
2.511	0.301000	0.588000	3.602445
-----	-----	-----	-----
16.860000		0.624024	6.126608
2.511	0.332000	0.644000	2.837849
-----	-----	-----	-----
17.000003		0.615621	4.406598
2.511	0.367000	0.564000	2.978086
-----	-----	-----	-----
16.810001		0.593780	5.280296
2.511	0.402000	0.617000	5.475259
-----	-----	-----	-----
16.870002		0.562247	8.874002
2.511	0.436000	0.508000	1.769340
-----	-----	-----	-----
16.750003		0.525693	3.482953
2.511	0.471000	0.536000	5.057186
-----	-----	-----	-----
16.660003		0.485428	9.435049

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.399

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.966



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.511	0.135000	0.446000	2.376252
-----	-----	-----	-----
14.870000		0.422237	5.327919
2.511	0.168000	0.480000	0.924533
-----	-----	-----	-----
14.870000		0.489245	1.926111
2.511	0.203000	0.545000	0.108611
-----	-----	-----	-----
15.230001		0.543913	0.199287
2.511	0.238000	0.627000	4.474688
-----	-----	-----	-----
15.150001		0.582253	7.136663
2.511	0.274000	0.598000	0.724959
-----	-----	-----	-----
15.030000		0.605249	1.212306
2.511	0.305000	0.569000	4.315960
-----	-----	-----	-----
15.110000		0.612139	7.585168
2.511	0.337000	0.627000	1.978123
-----	-----	-----	-----
14.920000		0.607218	3.154901
2.511	0.376000	0.660000	7.476736
-----	-----	-----	-----
15.000001		0.585232	11.328388
2.511	0.410000	0.577000	2.467048
-----	-----	-----	-----
15.000001		0.552329	4.275648
2.511	0.439000	0.530000	1.543593
-----	-----	-----	-----
15.000001		0.514564	2.912440
2.511	0.477000	0.421000	3.112632
-----	-----	-----	-----
15.070001		0.452126	7.393425

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.682

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.768

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	SMOOTHED DATA POINT	SCATTER PER CENT VAL,
2.511	0.159000	0.365000	2.793737
12.000001		0.392907	7.645856
2.511	0.175000	0.467000	1.129633
11.940000		0.478296	2.418915
2.511	0.211000	0.565000	3.091228
12.000001		0.534087	5.471200
2.511	0.237000	0.503000	5.448008
12.100000		0.557480	10.831031
2.511	0.279000	0.567000	0.115907
12.040000		0.568159	0.204421
2.511	0.318000	0.538000	1.331329
11.900001		0.551313	2.474590
2.511	0.354000	0.519000	0.309634
11.900001		0.515903	0.596597
2.511	0.385000	0.468000	0.423467
11.900001		0.472234	0.904844
2.511	0.421000	0.289000	11.958862
12.000001		0.408588	41.380149
2.511	0.458000	0.302000	2.937353
11.940000		0.331373	9.726335
2.511	0.492000	0.230000	2.233228
11.950000		0.252332	9.709686

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.888

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.305

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.191000	0.449000	3.536767
25.370002		0.484367	7.876987
2.59	0.256000	0.556000	2.023733
24.850002		0.576237	3.639807
2.59	0.312000	0.617000	0.395596
25.080001		0.613044	0.641160
2.59	0.385000	0.542000	5.779684
25.080001		0.599726	10.663623
2.59	0.450000	0.528000	0.905478
25.080001		0.537054	1.714920

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.528

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.907

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL,
2.59 -----	0.197000 -----	0.540000 -----	1.697480 -----
20.230003		0.523025	3.143483
2.59 -----	0.263000 -----	0.580000 -----	1.301777 -----
20.230003		0.593017	2.244444
2.59 -----	0.328000 -----	0.565000 -----	4.370964 -----
20.400001		0.608709	7.736219
2.59 -----	0.396000 -----	0.559000 -----	1.465440 -----
20.400001		0.573654	2.621538
2.59 -----	0.434000 -----	0.513000 -----	2.008426 -----
20.400001		0.533084	3.915061

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.168

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.932

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
2.59 ----- 16.900001	0.199000 -----	0.524000 ----- 0.513042	1.095748 ----- 2.091122
2.59 ----- 16.900001	0.265000 -----	0.584000 ----- 0.580467	0.353264 ----- 0.604905
2.59 ----- 16.670002	0.332000 -----	0.565000 ----- 0.573920	0.892090 ----- 1.578922
2.59 ----- 16.850002	0.400000 -----	0.480000 ----- 0.515432	3.543263 ----- 7.381799
2.59 ----- 16.530002	0.443000 -----	0.437000 ----- 0.463193	2.619391 ----- 5.994031

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.700

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.530

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.59	0.205000	0.475000	2.501100
-----	-----	-----	-----
14.550001		0.500011	5.265474
2.59	0.271000	0.543000	0.142324
-----	-----	-----	-----
14.420000		0.544423	0.262106
2.59	0.340000	0.557000	1.869201
-----	-----	-----	-----
14.240001		0.538308	3.355838
2.59	0.413000	0.449000	2.910608
-----	-----	-----	-----
14.300001		0.478106	6.482423
2.59	0.451000	0.388000	3.857440
-----	-----	-----	-----
14.050001		0.426574	9.941856

THE NUMBER OF DATA POINTS IS 5  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.256  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.061

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
2.59	0.210000	0.512000	3.137570
-----	-----	-----	-----
11.340000		0.480624	6.128067
2.59	0.279000	0.534000	3.261185
-----	-----	-----	-----
11.340000		0.501388	6.107089
2.59	0.354000	0.422000	2.433574
-----	-----	-----	-----
11.230001		0.446335	5.766763
2.59	0.418000	0.434000	8.092798
-----	-----	-----	-----
12.230001		0.353072	18.646999
2.59	0.443000	0.354000	4.545605
-----	-----	-----	-----
12.140001		0.308543	12.840692

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 4.294

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.897



## U.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.57	0.196000	0.472000	1.077711
24.870002		0.461222	2.283288
2.57	0.251000	0.530000	0.471222
25.910003		0.534712	0.889099
2.57	0.318000	0.572000	0.339651
25.700000		0.568603	0.593795
2.57	0.378000	0.568000	1.862168
25.290000		0.549378	3.278465
2.57	0.449000	0.471000	0.184631
25.290000		0.469153	0.391998

THE NUMBER OF DATA POINTS IS 5  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.787  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.487

# O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT E.F.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.195000	0.461000	2.000297
20.360000		0.481803	4.512577
2.57	0.263000	0.563000	1.256854
20.400001		0.550431	2.232432
2.57	0.328600	0.585000	2.257013
20.230003		0.562429	3.858143
2.57	0.397000	0.529000	0.529311
20.560001		0.523106	1.114009
2.57	0.461000	0.442000	0.144150
20.560001		0.443461	0.530657

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.265

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.404

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
2.57	0.200000	0.493000	0.445854
-----	-----	-----	-----
17.480003		0.497458	0.904370
-----	-----	-----	-----
2.57	0.270000	0.552000	0.493061
-----	-----	-----	-----
17.620002		0.556930	0.893227
-----	-----	-----	-----
2.57	0.334000	0.548000	1.014173
-----	-----	-----	-----
17.480003		0.537858	1.850690
-----	-----	-----	-----
2.57	0.846000	0.483000	0.051182
-----	-----	-----	-----
17.620002		0.483511	0.105967
-----	-----	-----	-----
2.57	0.470000	0.380000	1.446962
-----	-----	-----	-----
17.620002		0.365530	3.807796

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.690

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.512

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
2.57	0.203000	0.542000	1.803934
-----	-----	-----	-----
15.300001		0.523960	3.328293
2.57	0.274000	0.544000	0.394892
-----	-----	-----	-----
15.620000		0.547948	0.725905
2.57	0.341000	0.489000	3.472388
-----	-----	-----	-----
15.420000		0.523723	7.100998
2.57	0.409000	0.472000	1.523089
-----	-----	-----	-----
15.420000		0.456769	3.226884
2.57	0.478000	0.374000	2.455646
-----	-----	-----	-----
15.420000		0.349443	6.565898

THE NUMBER OF DATA POINTS IS 5

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.929

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.189

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.208000	0.543000	1.122284
12.210001		0.521777	2.066821
2.57	0.279000	0.521000	1.877308
12.340000		0.539773	3.603279
2.57	0.348000	0.464000	2.495688
12.340000		0.488956	5.378633
2.57	0.423000	0.376000	1.437229
12.360000		0.390372	3.822417
2.57	0.458000	0.341000	0.551337
12.210001		0.335486	1.616824

THE NUMBER OF DATA POINTS IS 5  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.496  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.297

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.112000	0.286000	0.027829
208.000030		0.285721	0.097305
4.15	0.167000	0.400000	0.374382
208.000030		0.403743	0.935956
4.15	0.221000	0.480000	0.840860
208.000030		0.488408	1.751793
4.15	0.111000	0.291000	0.774049
209.000030		0.283259	2.659965
4.15	0.167000	0.393000	1.074385
209.000030		0.403743	2.733806
4.15	0.224000	0.481000	1.126533
208.000030		0.492265	2.342066
4.15	0.289000	0.564000	0.836074
208.000030		0.555639	1.482401
4.15	0.339000	0.585000	0.475204
208.000030		0.580247	0.812314
4.15	0.392000	0.604000	1.770770
217.000030		0.586292	2.931739
4.15	0.421000	0.582000	0.014567
217.000030		0.581854	0.025029
4.15	0.397000	0.580000	0.589445
216.000030		0.585896	1.015629

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
4.15 ----- 216.000030	0.342000 -----	0.582000 ----- 0.581115	0.088405 ----- 0.151899
4.15 ----- 216.000030	0.284000 -----	0.525000 ----- 0.552075	2.707541 ----- 5.157221
4.15 ----- 216.000030	0.230000 -----	0.497000 ----- 0.499722	0.272238 ----- 0.547763
4.15 ----- 216.000030	0.175000 -----	0.447000 ----- 0.416165	2.883470 ----- 6.450716
4.15 ----- 216.000030	0.113000 -----	0.289000 ----- 0.288172	0.082784 ----- 0.286452

THE NUMBER OF DATA POINTS IS 16

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.871

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.236



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPERICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.116000	0.301000	0.314468
141.400024		0.304144	1.044744
4.15	0.175000	0.441000	2.061587
141.400024		0.420384	4.474801
4.15	0.229000	0.487000	0.741279
136.500030		0.494412	1.522133
4.15	0.290000	0.526000	1.910031
140.600018		0.545100	3.631236
4.15	0.349000	0.550000	1.518821
140.800018		0.565188	2.761494
4.15	0.407000	0.567000	0.558006
132.500030		0.561419	0.984139
4.15	0.350000	0.573000	0.767126
136.500030		0.565306	1.342260
4.15	0.292000	0.580000	3.377753
140.800018		0.546222	5.823765
4.15	0.231000	0.453000	4.360563
135.900024		0.496605	9.625967
4.15	0.177000	0.461000	3.734463
135.900024		0.423655	8.100790
4.15	0.119000	0.295000	1.601076
142.100006		0.311010	5.427377

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.904

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.085

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.119000	0.296000	0.820871
95.400009		0.302208	2.097540
4.15	0.173000	0.319000	8.012140
97.500015		0.399121	25.116428
4.15	0.234000	0.532000	5.195057
95.400009		0.480049	9.765146
4.15	0.297000	0.547000	2.408433
95.000015		0.522915	4.402986
4.15	0.356000	0.545000	2.790964
93.000015		0.517090	5.121025
4.15	0.398000	0.465000	1.638734
93.000015		0.491397	3.524160
4.15	0.353000	0.505000	1.858783
94.600006		0.518587	3.717564
4.15	0.277500	0.503000	1.991570
93.400009		0.522915	3.959384
4.15	0.234000	0.479000	0.104939
94.600006		0.480049	0.219081
4.15	0.175000	0.404000	0.170276
94.600006		0.402297	0.421481
4.15	0.119000	0.337000	3.676229
93.200012		0.300731	10.910625

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.586

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 6.245

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.120000	0.294000	1.473248
47.200004		0.308732	5.011048
4.15	0.190000	0.400000	2.446838
47.100006		0.395531	1.117095
4.15	0.244000	0.391000	1.253372
47.000007		0.403533	5.205556
4.15	0.309000	0.357000	0.441426
46.900001		0.361414	1.236487
4.15	0.370000	0.280000	0.594043
46.900001		0.285940	2.121585
4.15	0.348000	0.316000	0.017482
46.900001		0.315174	0.055322
4.15	0.305000	0.361000	0.432503
46.900003		0.365325	1.198070
4.15	0.265000	0.426000	2.272552
46.300003		0.403274	5.334630
4.15	0.186000	0.416000	2.493227
46.300003		0.393067	5.964657
4.15	0.122000	0.303000	0.959563
46.200003		0.312595	3.166875

THE NUMBER OF DATA POINTS IS 10

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.038

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.841

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.127000	0.273000	0.000321
23.000003		0.272996	0.001178
4.15	0.195000	0.344000	0.000774
22.900001		0.343992	0.002252

THE NUMBER OF DATA POINTS IS 2  
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.000  
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 0.001

## U.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.107000	0.282000	1.958072
197.000030		0.301580	6.943520
4.11	0.165000	0.413000	0.640213
198.700012		0.419402	1.550153
4.11	0.225000	0.485000	1.922172
197.000030		0.504221	3.963242
4.11	0.282000	0.573000	1.945114
197.000030		0.553548	3.394615
4.11	0.340000	0.559000	1.714730
199.500030		0.578147	3.067496
4.11	0.401000	0.578000	0.410723
199.500030		0.573892	0.710594
4.11	0.401000	0.549000	2.489281
199.500030		0.573892	4.534210
4.11	0.342000	0.582000	0.552570
199.700012		0.576474	0.949434
4.11	0.264000	0.578000	2.322936
197.800018		0.554770	4.018920
4.11	0.227000	0.533000	2.655351
199.500030		0.506446	4.981897
4.11	0.155000	0.418000	1.629358
198.700012		0.401706	3.877987

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.115000	0.312000	0.906403
-----	-----	-----	-----
197.800018		0.320064	2.584625

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.587

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.383

# O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.111000	0.290000	2.984233
149.600006		0.299842	3.393929
4.11	0.166000	0.401000	0.261116
149.600006		0.403611	0.451162
4.11	0.231000	0.494000	1.074901
149.600005		0.483231	2.179961
4.11	0.288000	0.516000	0.300193
146.300018		0.519001	0.501653
4.11	0.348000	0.555000	2.425449
149.600006		0.526745	5.390989
4.11	0.403000	0.488000	2.269727
149.600006		0.510697	4.651080
4.11	0.419000	0.507000	2.460075
149.600006		0.502391	0.909023
4.11	0.405000	0.489000	2.074301
149.600006		0.509743	4.741925
4.11	0.397000	0.537000	2.358018
149.600006		0.513411	4.392583
4.11	0.335000	0.542000	1.455140
149.600006		0.527448	2.684761
4.11	0.294000	0.492000	2.988444
147.700012		0.521084	5.911473

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
4.11	0.234000	0.476000	0.986832
-----	-----	-----	-----
149.600006		0.485868	2.073177
4.11	0.173000	0.424000	0.966328
-----	-----	-----	-----
149.600006		0.414336	2.279076
4.11	0.118000	0.322000	0.696498
-----	-----	-----	-----
150.200012		0.315035	2.163038

THE NUMBER OF DATA POINTS IS 14

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.401

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.943



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.234000	0.476000	0.986832
-----	-----	-----	-----
149.600006		0.485868	2.073177
4.11	0.173000	0.424000	0.966328
-----	-----	-----	-----
149.600006		0.414336	2.279076
4.11	0.118000	0.322000	0.696498
-----	-----	-----	-----
150.200012		0.315035	2.163038

THE NUMBER OF DATA POINTS IS 14

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.401

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.943

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
4.11	0.351000	0.518000	0.819242
-----	-----	-----	-----
100.500015		0.526192	1.581548
4.11	0.296000	0.506000	1.933098
-----	-----	-----	-----
100.100006		0.525331	1.820352
4.11	0.232000	0.499000	2.051856
-----	-----	-----	-----
100.500015		0.478381	1.931970
4.11	0.176000	0.385000	1.930701
-----	-----	-----	-----
100.500015		0.404307	5.014810
4.11	0.120000	0.293000	1.352310
-----	-----	-----	-----
100.500015		0.306523	4.615393
4.11	0.113000	0.300000	0.703013
-----	-----	-----	-----
99.700012		0.292969	2.343377
4.11	0.168000	0.411000	1.936835
-----	-----	-----	-----
99.700012		0.391631	4.712494
4.11	0.231000	0.500000	2.269423
-----	-----	-----	-----
99.700012		0.477305	4.538846
4.11	0.289000	0.501000	2.144420
-----	-----	-----	-----
99.700012		0.522444	4.280281
4.11	0.348000	0.517000	1.020241
-----	-----	-----	-----
95.700012		0.527202	1.973386
4.11	0.411000	0.491000	1.342273
-----	-----	-----	-----
99.700012		0.477577	2.733753

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
4.11	0.426000	0.464000	0.759470
-----	-----	-----	-----
100.100006		0.456405	1.636790
4.11	0.411000	0.479000	0.142270
-----	-----	-----	-----
96.120010		0.477577	0.297015

THE NUMBER OF DATA POINTS IS 13

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.416

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.206

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.115000	0.271000	2.286502
80.100006		0.248134	8.437280
4.11	0.173000	0.316000	1.103657
77.200012		0.304963	3.492587
4.11	0.237000	0.368000	2.394062
72.500015		0.344059	6.505604
4.11	0.310000	0.317000	3.104883
76.500015		0.348048	9.794586
4.11	0.352000	0.345000	1.885903
74.200012		0.326141	5.466385
4.11	0.420000	0.233000	1.291632
76.900009		0.245916	5.543488
4.11	0.408000	0.276000	1.155573
79.100006		0.264444	4.186860
4.11	0.354000	0.328000	0.339782
74.200012		0.324602	1.035921
4.11	0.314000	0.344000	0.278616
76.900009		0.346786	0.809930
4.11	0.238000	0.338000	0.643116
77.200012		0.344431	1.902710
4.11	0.179000	0.298000	1.179933
74.800003		0.309799	3.959508

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
4.11	0.120000	0.227000	2.667051
-----	-----	-----	-----
74.800003		0.253670	11.749126

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.527

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.240

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL,
4.11 ----- 59.800003	0.121000 -----	0.245000 ----- 0.224540	2.045956 ----- 8.350843
4.11 ----- 59.800003	0.179000 -----	0.289000 ----- 0.312094	2.309406 ----- 7.991024
4.11 ----- 59.800003	0.242000 -----	0.374000 ----- 0.339106	3.489309 ----- 9.329706
4.11 ----- 59.800003	0.303000 -----	0.304000 ----- 0.313053	0.905364 ----- 2.978174
4.11 ----- 59.800003	0.365000 -----	0.268000 ----- 0.249756	1.824370 ----- 6.807352
4.11 ----- 59.800003	0.420000 -----	0.165000 ----- 0.175312	1.031234 ----- 6.249908
4.11 ----- 59.800003	0.429000 -----	0.170000 ----- 0.162302	0.769722 ----- 4.527779
4.11 ----- 59.800003	0.363000 -----	0.243000 ----- 0.252215	0.921547 ----- 3.792377
4.11 ----- 59.800003	0.299000 -----	0.301000 ----- 0.316030	1.503062 ----- 4.993562
4.11 ----- 59.800003	0.237000 -----	0.338000 ----- 0.339178	0.117814 ----- 0.348563
4.11 ----- 59.800003	0.182000 -----	0.316000 ----- 0.314865	0.113433 ----- 0.358967

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.121000	0.210000	1.454043
-----	-----	-----	-----
59.800003		0.224540	6.924016

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.373

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.221

# O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
4.11 ----- 50.100006	0.124000 -----	0.324000 ----- 0.308433	1.556653 ----- 4.804485
4.11 ----- 50.100006	0.184000 -----	0.302000 ----- 0.399730	9.773004 ----- 32.360939
4.11 ----- 50.100006	0.247000 -----	0.401000 ----- 0.423267	2.226770 ----- 5.553043
4.11 ----- 49.900001	0.305000 -----	0.339000 ----- 0.393646	5.464679 ----- 16.119998
4.11 ----- 49.900001	0.371000 -----	0.305000 ----- 0.317247	1.224780 ----- 4.015673
4.11 ----- 50.100006	0.426000 -----	0.242000 ----- 0.232192	0.980717 ----- 4.052550
4.11 ----- 49.900001	0.442000 -----	0.202000 ----- 0.205539	0.353980 ----- 1.752376
4.11 ----- 49.900001	0.429000 -----	0.243000 ----- 0.227236	1.576388 ----- 6.487194
4.11 ----- 49.900001	0.369000 -----	0.317000 ----- 0.320055	0.305581 ----- 0.963978
4.11 ----- 49.900001	0.303000 -----	0.438000 ----- 0.395337	4.266232 ----- 9.740257
4.11 ----- 49.900001	0.242000 -----	0.482000 ----- 0.423723	5.827659 ----- 12.090580



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
4.11	0.184000	0.421000	2.126992
-----	-----	-----	-----
50.100006		0.399730	5.052238
-----	-----	-----	-----
4.11	0.123000	0.337000	3.074205
-----	-----	-----	-----
50.300053		0.306257	9.122272

THE NUMBER OF DATA POINTS IS 13

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.981

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.624

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
4.11	0.123000	0.249000	0.567817
-----	-----	-----	-----
39.900001		0.243321	2.280392
4.11	0.189000	0.291000	1.092630
-----	-----	-----	-----
39.900001		0.280073	3.754745
4.11	0.247000	0.304000	3.844291
-----	-----	-----	-----
39.900001		0.265557	12.645696
4.11	0.306000	0.207000	0.370919
-----	-----	-----	-----
39.900001		0.210709	1.791882
4.11	0.371000	0.123000	1.388141
-----	-----	-----	-----
39.900001		0.109118	11.285703
4.11	0.426000	0.000000	0.601351
-----	-----	-----	-----
39.900001		-0.006013	0.601351
4.11	0.378000	0.072000	2.385756
-----	-----	-----	-----
39.900001		0.095857	33.135505
4.11	0.308000	0.209000	0.080266
-----	-----	-----	-----
39.900001		0.208197	0.384050
4.11	0.249000	0.247000	1.733345
-----	-----	-----	-----
39.900001		0.264333	7.017591
4.11	0.185000	0.248000	3.151962
-----	-----	-----	-----
39.900001		0.279519	12.709524
4.11	0.123000	0.244000	0.067818
-----	-----	-----	-----
39.900001		0.243321	0.277943

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.389

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 7.807

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL,
4.11	0.128000	0.253000	0.670069
-----	-----	-----	-----
25.200000		0.259700	2.648496
4.11	0.192000	0.332000	1.819664
-----	-----	-----	-----
24.900001		0.313803	5.480917
4.11	0.256000	0.263000	1.012605
-----	-----	-----	-----
25.200000		0.273126	3.850211
4.11	0.297000	0.179000	1.292356
-----	-----	-----	-----
25.200000		0.191923	7.219870
4.11	0.314000	0.140000	0.474229
-----	-----	-----	-----
25.200000		0.144742	3.387353
4.11	0.322000	0.119000	0.070174
-----	-----	-----	-----
25.100002		0.119701	0.589697
4.11	0.336000	0.078000	0.657673
-----	-----	-----	-----
25.200000		0.071423	8.431707
4.11	0.288000	0.229000	1.535990
-----	-----	-----	-----
24.900001		0.213640	6.707384
4.11	0.258000	0.271000	0.079822
-----	-----	-----	-----
25.000003		0.270201	0.294548
4.11	0.193000	0.305000	0.892663
-----	-----	-----	-----
24.900001		0.313926	2.926764
4.11	0.128000	0.263000	0.329929
-----	-----	-----	-----
25.000003		0.259700	1.254485

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.803

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.890

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
4.7	0.175000	0.461000	3.085804
-----	-----	-----	-----
203.200012		0.430141	6.693718
-----	-----	-----	-----
4.7	0.114000	0.323000	1.559639
-----	-----	-----	-----
199.800018		0.307403	4.828604

THE NUMBER OF DATA POINTS IS 13

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.288

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.782

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.116000	0.315000	0.145942
----- 153.700012	-----	0.316459	0.463307
4.7	0.175000	0.413000	2.531719
----- 153.700012	-----	0.438317	6.130071
4.7	0.231000	0.498000	1.968461
----- 152.100006	-----	0.517684	3.952734
4.7	0.293000	0.565000	0.384855
----- 150.200012	-----	0.568848	0.681159
4.7	0.349000	0.538000	4.792440
----- 152.400024	-----	0.585924	8.907880
4.7	0.408000	0.514000	6.419397
----- 152.100006	-----	0.578194	12.489101
4.7	0.438000	0.554000	1.149404
----- 152.400024	-----	0.565494	2.074737
4.7	0.408000	0.565000	8.680606
----- 152.400024	-----	0.578194	13.053543
4.7	0.349000	0.615000	2.907550
----- 152.400024	-----	0.585924	4.727725
4.7	0.291000	0.588000	2.024853
----- 155.400024	-----	0.567751	3.443628
4.7	0.235000	0.531000	0.889897
----- 152.400024	-----	0.522101	1.675889

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
4.7 ----- 152.400024	0.175000 -----	0.462000 ----- 0.428317	2.368277 ----- 5.126141
4.7 ----- 160.200012	0.116000 -----	0.322000 ----- 0.316459	0.554055 ----- 1.720667

THE NUMBER OF DATA POINTS IS 13  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.678  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.957

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.118000	0.331000	0.209218
100.100006		0.333092	0.632079
4.7	0.175000	0.395000	3.140968
101.000015		0.426409	7.951818
4.7	0.237000	0.483000	1.915711
99.900009		0.502157	3.966276
4.7	0.294000	0.549000	0.854468
100.100006		0.540455	1.556409
4.7	0.357000	0.533000	0.602245
101.000015		0.539022	1.129916
4.7	0.412000	0.482000	1.091420
100.100006		0.492914	2.264358
4.7	0.412000	0.498000	0.508576
100.100006		0.492914	1.021238
4.7	0.359000	0.544000	0.587725
99.300003		0.538122	1.080378
4.7	0.297000	0.551000	0.950169
100.100006		0.541498	1.724445
4.7	0.180000	0.476000	4.237342
100.300003		0.433626	8.901981
4.7	0.120000	0.335000	0.166773
100.300003		0.336667	0.497832

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.296

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.793

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
4.7 ----- 50.300003	0.123000 -----	0.345000 ----- 0.336229	0.877082 ----- 2.542268
4.7 ----- 50.500007	0.186000 -----	0.365000 ----- 0.430876	6.587649 ----- 18.048355
4.7 ----- 50.300003	0.246000 -----	0.443000 ----- 0.448154	0.515461 ----- 1.163548
4.7 ----- 50.200004	0.306000 -----	0.372000 ----- 0.409088	3.708797 ----- 9.969886
4.7 ----- 50.300003	0.371000 -----	0.283000 ----- 0.319997	3.699714 ----- 13.073194
4.7 ----- 50.800003	0.428000 -----	0.201000 ----- 0.216002	1.500275 ----- 7.464058
4.7 ----- 50.800003	0.433000 -----	0.220000 ----- 0.206167	1.383292 ----- 6.287694
4.7 ----- 50.300003	0.365000 -----	0.342000 ----- 0.329787	1.221227 ----- 3.570841
4.7 ----- 50.500007	0.306000 -----	0.467000 ----- 0.409088	5.791199 ----- 12.400856
4.7 ----- 50.300003	0.247000 -----	0.502000 ----- 0.447925	5.407494 ----- 10.771900
4.7 ----- 50.200004	0.185000 -----	0.444000 ----- 0.430028	1.397150 ----- 3.146736



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.123000	0.336000	0.022917
-----	-----	-----	-----
50.200004		0.336229	0.068208

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.676

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 7.375

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
4.7	0.128000	0.274000	1.261413
25.000003	-----	0.286614	4.603697
4.7	0.194000	0.310000	3.245861
25.100002	-----	0.342468	10.473749
4.7	0.255000	0.294000	1.774305
25.100002	-----	0.311743	6.035052
4.7	0.322000	0.165000	0.963401
25.200000	-----	0.174634	5.838799
4.7	0.337000	0.153000	2.517599
25.100002	-----	0.127824	16.454895
4.7	0.321000	0.145000	3.253743
25.100002	-----	0.177537	22.439609
4.7	0.256000	0.364000	5.347783
25.100002	-----	0.310522	14.691711
4.7	0.194000	0.349000	0.653141
25.100002	-----	0.342468	1.871466
4.7	0.129000	0.308000	1.990872
25.100002	-----	0.288091	6.463872

THE NUMBER OF DATA POINTS IS 9

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.334

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.874

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'A'	0.194000	0.469000	1.522112
23.720001		0.453778	3.45441
PLUG 'A'	0.191000	0.484000	3.433180
23.470001		0.449668	7.093347
PLUG 'A'	0.190000	0.458000	0.973266
23.400001		0.448267	2.125036
PLUG 'A'	0.259000	0.526000	0.598847
23.580001		0.520011	1.138494
PLUG 'A'	0.259000	0.525000	0.495266
23.540000		0.520047	0.943365
PLUG 'A'	0.322000	0.568000	3.363895
24.250003		0.534361	5.922351
PLUG 'A'	0.324000	0.574000	3.973877
24.550003		0.534261	6.923132
PLUG 'A'	0.390000	0.505000	0.034439
24.850002		0.505344	0.068197
PLUG 'A'	0.390000	0.511000	0.624299
24.480003		0.504757	1.221720
PLUG 'A'	0.456000	0.447000	0.827282
24.290000		0.438727	1.850744
PLUG 'A'	0.457000	0.466000	2.843857
24.310001		0.437561	6.102698

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL,
PLUG 'A'	0.389000	0.582000	7.705677
----- 24.110000	-----	----- 0.504943	----- 13.239995
PLUG 'A'	0.325000	0.488000	4.596287
----- 24.210002	-----	----- 0.533962	----- 9.418621
PLUG 'A'	0.260000	0.565000	4.470742
----- 24.830001	-----	----- 0.520292	----- 7.912817
PLUG 'A'	0.195000	0.505000	5.003578
----- 24.000003	-----	----- 0.454964	----- 9.908075
PLUG 'A'	0.130000	0.296000	3.352022
----- 24.480003	-----	----- 0.329520	----- 11.724401
PLUG 'A'	0.129000	0.331000	0.389099
----- 24.530002	-----	----- 0.327109	----- 1.175526
PLUG 'A'	0.127000	0.322000	0.028473
----- 24.660003	-----	----- 0.322284	----- 0.088425
PLUG 'A'	0.126000	0.320000	0.019997
----- 24.660003	-----	----- 0.319800	----- 0.062491
PLUG 'A'	0.192000	0.467000	1.660502
----- 24.580001	-----	----- 0.450394	----- 3.555679
PLUG 'A'	0.191000	0.446000	0.290006
----- 24.580001	-----	----- 0.448900	----- 0.650238
PLUG 'A'	0.257000	0.515000	0.337910
----- 24.450000	-----	----- 0.518379	----- 0.656137

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.257000	0.516000	0.240528
24.660003	-----	0.518405	0.466140
PLUG 'A'	0.325000	0.489000	4.507041
24.450000	-----	0.534070	9.216854
PLUG 'A'	0.324000	0.489000	4.533053
24.660003	-----	0.534330	9.270048
PLUG 'A'	0.389000	0.511000	0.52 52
24.660003	-----	0.505771	1.023193
PLUG 'A'	0.390000	0.505000	0.006961
24.680000	-----	0.505069	0.013785
PLUG 'A'	0.458000	0.421000	1.671159
24.760002	-----	0.437711	3.969500
PLUG 'A'	0.445000	0.450000	0.231963
24.470001	-----	0.452319	0.515474
PLUG 'A'	0.383000	0.516000	0.614619
24.560001	-----	0.509853	1.191123
PLUG 'A'	0.326000	0.539000	0.506401
24.470001	-----	0.533936	0.939519
PLUG 'A'	0.258000	0.519000	0.000250
24.370002	-----	0.519002	0.000482
PLUG 'A'	0.196000	0.449000	0.723064
24.370002	-----	0.456230	1.610387

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'A'	0.129000	0.339000	1.186532
-----	-----	-----	-----
24.570003		0.327134	3.500093
PLUG 'A'	0.124000	0.332000	1.736718
-----	-----	-----	-----
24.450000		0.314632	5.231081
PLUG 'A'	0.191000	0.428000	2.092606
-----	-----	-----	-----
24.250003		0.448926	4.889266
PLUG 'A'	0.254000	0.507000	0.949645
-----	-----	-----	-----
24.740001		0.516496	1.873067
PLUG 'A'	0.323000	0.536000	0.172448
-----	-----	-----	-----
24.330001		0.534275	0.321731
PLUG 'A'	0.384000	0.527000	1.787507
-----	-----	-----	-----
24.530002		0.509124	3.391855
PLUG 'A'	0.449000	0.430000	1.873964
-----	-----	-----	-----
24.850002		0.448739	4.358057
PLUG 'A'	0.448000	0.429000	2.001017
-----	-----	-----	-----
24.530002		0.449010	4.664376
PLUG 'A'	0.389000	0.523000	1.719701
-----	-----	-----	-----
24.680000		0.505802	3.288148
PLUG 'A'	0.256000	0.539000	2.124917
-----	-----	-----	-----
24.530002		0.517750	3.942333
PLUG 'A'	0.194000	0.405000	4.833120
-----	-----	-----	-----
24.450000		0.453331	11.933630

THE NUMBER OF DATA POINTS IS 44

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.831

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.869

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.131000	0.341000	0.361967
20.160003		0.344619	1.061487
PLUG 'A'	0.199000	0.445000	2.438575
20.430000		0.469385	5.479944
PLUG 'A'	0.265000	0.549000	2.108252
20.060001		0.527917	3.840163
PLUG 'A'	0.332000	0.477000	5.374253
20.330001		0.530742	11.266777
PLUG 'A'	0.402000	0.574000	9.159368
20.060001		0.482406	15.957088
PLUG 'A'	0.464000	0.388000	1.731258
20.060001		0.405312	4.462007
PLUG 'A'	0.465000	0.393000	1.120615
20.100002		0.404206	2.851438
PLUG 'A'	0.401000	0.539000	5.538088
20.100002		0.483619	10.274747
PLUG 'A'	0.332000	0.476000	5.457426
20.230003		0.530574	11.465181
PLUG 'A'	0.264000	0.468000	5.941206
20.130001		0.527412	12.694885
PLUG 'A'	0.199000	0.504000	3.323591
20.000003		0.470764	6.594427

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'A'	0.132000	0.377000	2.920168
20.000003	-----	0.347798	7.745805
PLUG 'A'	0.130000	0.373000	3.132599
20.270000	-----	0.341674	8.398391
PLUG 'A'	0.130000	0.344000	0.097137
20.000003	-----	0.343028	0.282377
PLUG 'A'	0.196000	0.461000	0.407439
20.500003	-----	0.465074	0.883816
PLUG 'A'	0.132000	0.329000	2.117413
19.530002	-----	0.350174	6.435906
PLUG 'A'	0.328000	0.584000	5.358148
19.530002	-----	0.530418	9.174911
PLUG 'A'	0.198000	0.450000	2.101832
19.490001	-----	0.471018	4.670739
PLUG 'A'	0.400000	0.478000	0.329911
19.530002	-----	0.481299	0.690191
PLUG 'A'	0.456000	0.406000	0.616729
19.550003	-----	0.412167	1.519037
PLUG 'A'	0.401000	0.461000	1.842957
19.400001	-----	0.479429	3.997739
PLUG 'A'	0.329000	0.516000	1.374972
19.400001	-----	0.529749	2.664674



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'A'	0.265000	0.517000	1.132023
-----	-----	-----	-----
19.400001		0.528320	2.189600
-----	-----	-----	-----
PLUG 'A'	0.130000	0.366000	1.954347
-----	-----	-----	-----
19.330001		0.346456	5.339746
-----	-----	-----	-----
PLUG 'A'	0.263000	0.593000	6.559122
-----	-----	-----	-----
19.560001		0.527408	11.060915
-----	-----	-----	-----
PLUG 'A'	0.198000	0.453000	1.828706
-----	-----	-----	-----
19.400001		0.471287	4.036880

THE NUMBER OF DATA POINTS IS 26

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.858

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.963

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.132000	0.350000	1.091307
17.280002		0.360913	3.118021
PLUG 'A'	0.201000	0.499000	1.965391
17.280002		0.479346	3.938661
PLUG 'A'	0.268000	0.529000	0.319147
16.980003		0.525808	0.603302
PLUG 'A'	0.336000	0.458000	5.755139
17.170002		0.515551	12.565807
PLUG 'A'	0.406000	0.459000	0.577128
17.220001		0.453228	1.257359
PLUG 'A'	0.480000	0.326000	1.191914
17.040000		0.337919	3.656178
PLUG 'A'	0.472000	0.363000	0.662118
17.280002		0.356378	1.824017
PLUG 'A'	0.408000	0.453000	0.899112
16.720001		0.444008	1.984795
PLUG 'A'	0.337000	0.547000	3.254867
17.100002		0.514451	5.950397
PLUG 'A'	0.268000	0.483000	4.280847
16.980003		0.525808	8.863037
PLUG 'A'	0.203000	0.535000	5.324441
17.140003		0.481755	9.952228

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.134000	0.359000	0.698167
17.140003		0.365981	1.944755
PLUG 'A'	0.129000	0.358000	0.225794
16.850002		0.355742	0.630710
PLUG 'A'	0.196000	0.456000	1.755070
16.850002		0.473550	3.848839
PLUG 'A'	0.261000	0.514000	1.012695
17.080001		0.524127	1.970223
PLUG 'A'	0.329000	0.489000	2.841163
16.940002		0.517411	5.810149
PLUG 'A'	0.396000	0.454000	1.053422
17.180000		0.464534	2.320314
PLUG 'A'	0.464000	0.341000	2.719653
17.180000		0.368196	7.975522
PLUG 'A'	0.462000	0.350000	1.730555
16.940002		0.367305	4.944444
PLUG 'A'	0.399000	0.451000	0.745005
16.970001		0.458460	1.654114
PLUG 'A'	0.331000	0.499000	1.959336
17.230003		0.518593	3.926525
PLUG 'A'	0.265000	0.507000	1.911366
17.330001		0.526113	3.769953

THE NUMBER OF DATA POINTS IS 22

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.907

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.204

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'A'	0.137000	0.373000	0.461655
-----	-----	-----	-----
14.870000		0.377616	1.237683
PLUG 'A'	0.137000	0.384000	0.638342
-----	-----	-----	-----
14.870000		0.377616	1.662348
PLUG 'A'	0.138000	0.376000	0.360971
-----	-----	-----	-----
15.020000		0.379609	0.960031
PLUG 'A'	0.206000	0.520000	3.854447
-----	-----	-----	-----
15.000001		0.481455	7.412399
PLUG 'A'	0.275000	0.555000	4.244709
-----	-----	-----	-----
14.810001		0.512552	7.648125
PLUG 'A'	0.344000	0.485000	0.169694
-----	-----	-----	-----
14.810001		0.483303	0.349885
PLUG 'A'	0.412000	0.463000	5.315703
-----	-----	-----	-----
15.070001		0.409843	11.480999
PLUG 'A'	0.480000	0.330000	3.250551
-----	-----	-----	-----
15.260000		0.297494	9.850156
PLUG 'A'	0.414000	0.442000	3.655714
-----	-----	-----	-----
15.000001		0.405442	8.270847
PLUG 'A'	0.343000	0.479000	1.058453
-----	-----	-----	-----
15.180000		0.489584	2.209714
PLUG 'A'	0.207000	0.501000	1.858461
-----	-----	-----	-----
15.000001		0.482415	3.709503

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.140000	0.342000	4.172021
-----	-----	-----	-----
14.760000		0.383720	12.198894

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.420

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.582

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'A'	0.139000	0.372000	0.010406
-----	-----	-----	-----
11.960001		0.371895	0.027975
PLUG 'A'	0.211000	0.471000	1.130092
-----	-----	-----	-----
12.000001		0.459699	2.399346
PLUG 'A'	0.280000	0.490000	2.006334
-----	-----	-----	-----
12.000001		0.469936	4.094559
PLUG 'A'	0.351000	0.411000	0.767797
-----	-----	-----	-----
12.100000		0.418677	1.868120
PLUG 'A'	0.423000	0.250000	5.592239
-----	-----	-----	-----
12.020000		0.305922	22.368957
PLUG 'A'	0.491000	0.154000	0.243106
-----	-----	-----	-----
11.940000		0.156431	1.578613
PLUG 'A'	0.422000	0.353000	4.520828
-----	-----	-----	-----
12.020000		0.307791	12.806877
PLUG 'A'	0.350000	0.374000	4.361433
-----	-----	-----	-----
12.020000		0.417614	11.661584
PLUG 'A'	0.211000	0.471000	1.130092
-----	-----	-----	-----
12.000001		0.459699	2.399346
PLUG 'A'	0.140000	0.365000	0.914609
-----	-----	-----	-----
12.020000		0.374146	2.505779

THE NUMBER OF DATA POINTS IS 10

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.067

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 6.171

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL,
PLUG 'B'	0.125000	0.345000	1.333141
24.950000	-----	0.358331	3.864178
PLUG 'B'	0.189000	0.469000	1.109820
24.850002	-----	0.480098	2.366355
PLUG 'B'	0.256000	0.574000	4.051411
24.870002	-----	0.533485	7.058208
PLUG 'B'	0.316000	0.518000	0.539076
24.850002	-----	0.523390	1.040688
PLUG 'B'	0.393000	0.455000	1.084596
24.950000	-----	0.444154	2.383727
PLUG 'B'	0.456000	0.351000	1.752341
25.060001	-----	0.333476	4.992424
PLUG 'B'	0.453000	0.325000	1.024371
24.750003	-----	0.335243	3.151912
PLUG 'B'	0.390000	0.488000	3.946513
24.950000	-----	0.448534	8.087118
PLUG 'B'	0.323000	0.509000	0.908124
24.750003	-----	0.518081	1.784134
PLUG 'B'	0.318000	0.521000	0.392043
25.120002	-----	0.524920	0.752483
PLUG 'B'	0.253000	0.595000	6.312991
24.790000	-----	0.531870	10.610069

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
PLUG 'B'	0.192000	0.509000	2.595603
-----	-----	-----	-----
24.750003		0.483043	5.099418
-----	-----	-----	-----
PLUG 'B'	0.130000	0.387000	1.881230
-----	-----	-----	-----
24.750003		0.368187	4.861060

THE NUMBER OF DATA POINTS IS 13  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.071  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.311



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'B'	0.130000	0.392000	4.378623
20.350002	-----	0.348213	11.169956
PLUG 'B'	0.197000	0.488000	1.588589
20.400001	-----	0.472114	3.255305
PLUG 'B'	0.254000	0.515000	0.290215
20.160003	-----	0.512097	0.563524
PLUG 'B'	0.324000	0.501000	1.263445
20.100002	-----	0.488365	2.521848
PLUG 'B'	0.392000	0.400000	0.237554
20.440002	-----	0.402375	0.593685
PLUG 'B'	0.455000	0.248000	1.836320
20.060001	-----	0.266363	7.404519
PLUG 'B'	0.456000	0.299000	3.189665
20.260002	-----	0.267103	10.667778
PLUG 'B'	0.400000	0.439000	5.765301
19.800003	-----	0.381347	13.112806
PLUG 'B'	0.326000	0.484000	0.315880
20.200000	-----	0.487158	0.652646
PLUG 'B'	0.265000	0.481000	3.174210
19.830001	-----	0.512742	6.599189
PLUG 'B'	0.194000	0.470000	0.160455
20.400001	-----	0.468395	0.341395

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.129000	0.345000	0.106358
20.000003		0.346063	0.108285

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.858

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.767

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'B'	0.130000	0.327000	2.909088
-----	-----	-----	-----
16.550003		0.356090	8.896295
PLUG 'B'	0.201000	0.472000	0.439053
-----	-----	-----	-----
16.730003		0.476390	0.930198
PLUG 'B'	0.270000	0.422000	7.801348
-----	-----	-----	-----
16.630001		0.500013	18.486606
PLUG 'B'	0.330000	0.392000	6.875635
-----	-----	-----	-----
17.270000		0.461756	17.495258
PLUG 'B'	0.400000	0.316000	1.857513
-----	-----	-----	-----
16.640003		0.334575	5.878207
PLUG 'B'	0.468000	0.207000	2.532193
-----	-----	-----	-----
17.520000		0.181678	12.232816
PLUG 'B'	0.401000	0.334000	0.398695
-----	-----	-----	-----
16.520000		0.330013	1.193699
PLUG 'B'	0.334000	0.513000	6.379097
-----	-----	-----	-----
16.590000		0.449208	12.434890
PLUG 'B'	0.267000	0.551000	5.020010
-----	-----	-----	-----
16.640003		0.500800	9.110727
PLUG 'B'	0.202000	0.492000	1.496321
-----	-----	-----	-----
16.540000		0.477036	3.041303
PLUG 'B'	0.132000	0.372000	1.112526
-----	-----	-----	-----
16.570003		0.360874	2.990663

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.347

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.426

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'B'	0.133000	0.395000	3.083402
-----	-----	-----	-----
14.920000		0.364166	7.806080
PLUG 'B'	0.202000	0.491000	2.013522
-----	-----	-----	-----
14.850000		0.470864	4.100860
PLUG 'B'	0.266000	0.505000	1.765382
-----	-----	-----	-----
15.070001		0.487346	3.495806
PLUG 'B'	0.334000	0.450000	2.744418
-----	-----	-----	-----
14.850000		0.422555	6.098707
PLUG 'B'	0.405000	0.284000	0.113880
-----	-----	-----	-----
14.910001		0.282861	0.400988
PLUG 'B'	0.447000	0.140000	2.910027
-----	-----	-----	-----
14.940000		0.169100	20.785907
PLUG 'B'	0.402000	0.317000	2.977103
-----	-----	-----	-----
14.800001		0.287229	9.391492
PLUG 'B'	0.334000	0.423000	0.229418
-----	-----	-----	-----
15.000001		0.425294	0.542360
PLUG 'B'	0.272000	0.472000	1.248479
-----	-----	-----	-----
14.960001		0.484484	2.645082
PLUG 'B'	0.202000	0.476000	0.496524
-----	-----	-----	-----
14.880001		0.471034	1.043119
PLUG 'B'	0.136000	0.375000	0.415414
-----	-----	-----	-----
14.850000		0.370845	1.107772

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.636

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.219

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.139000	0.361000	0.161898
12.040000		0.362618	0.448471
PLUG 'B'	0.208000	0.444000	0.066715
11.970001		0.443332	0.150260
PLUG 'B'	0.278000	0.459000	3.138119
12.000001		0.427618	6.836860
PLUG 'B'	0.345000	0.336000	0.542932
12.040000		0.330570	1.615871
PLUG 'B'	0.399000	0.184000	1.552516
12.040000		0.199525	8.437589
PLUG 'B'	0.347000	0.334000	0.749468
12.040000		0.326505	2.243918
PLUG 'B'	0.278000	0.429000	0.037205
12.070001		0.429372	0.086725
PLUG 'B'	0.210000	0.424000	2.071047
12.000001		0.444710	4.884545
PLUG 'B'	0.140000	0.356000	0.834715
12.020000		0.364347	2.344706

THE NUMBER OF DATA POINTS IS 9

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.017

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.005

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'C'	0.129000	0.460000	10.589921
24.580001	-----	0.354100	23.021568
PLUG 'C'	0.253000	0.706000	14.959146
24.910003	-----	0.556408	21.188591
PLUG 'C'	0.385000	0.665000	17.418785
25.310001	-----	0.490812	26.193660
PLUG 'C'	0.454000	0.423000	8.479583
24.700000	-----	0.338204	20.046295
PLUG 'C'	0.384000	0.599000	10.888463
25.230003	-----	0.490115	18.177734
PLUG 'C'	0.253000	0.654000	7.278371
25.820003	-----	0.581216	11.129009
PLUG 'C'	0.126000	0.386000	2.622807
25.230003	-----	0.359771	6.794837
PLUG 'C'	0.126000	0.339000	1.101422
24.800003	-----	0.350014	3.249033
PLUG 'C'	0.190000	0.462000	3.002083
24.880001	-----	0.492020	6.498017
PLUG 'C'	0.254000	0.524000	3.892970
25.160003	-----	0.562929	7.429333
PLUG 'C'	0.315000	0.494000	6.174255
25.000003	-----	0.555742	12.498493

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
PLUG 'C'	0.381000	0.447000	4.571336
-----	-----	-----	-----
25.160003		0.492713	10.226703
PLUG 'C'	0.446000	0.322000	5.980683
-----	-----	-----	-----
25.590000		0.381806	16.573551
PLUG 'C'	0.446000	0.332000	4.496091
-----	-----	-----	-----
25.430000		0.376960	13.542444
PLUG 'C'	0.383000	0.456000	3.729129
-----	-----	-----	-----
25.290000		0.493291	8.177915
PLUG 'C'	0.320000	0.508000	4.689133
-----	-----	-----	-----
25.080001		0.554891	9.230579
PLUG 'C'	0.257000	0.535000	2.524257
-----	-----	-----	-----
25.000003		0.560242	4.718237
PLUG 'C'	0.192000	0.453000	5.122066
-----	-----	-----	-----
25.260002		0.504220	11.306989
PLUG 'C'	0.129000	0.333000	3.224855
-----	-----	-----	-----
25.110000		0.365248	9.684253

THE NUMBER OF DATA POINTS IS 19

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 6.355

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 12.720

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'C'	0.130000	0.346000	0.212663
-----	-----	-----	-----
19.930000		0.348126	0.614634
PLUG 'C'	0.198000	0.456000	1.954239
-----	-----	-----	-----
19.970001		0.475542	4.285614
PLUG 'C'	0.263000	0.485000	3.262659
-----	-----	-----	-----
20.000003		0.517626	6.727152
PLUG 'C'	0.326000	0.463000	2.858704
-----	-----	-----	-----
20.150001		0.491587	6.174307
PLUG 'C'	0.395000	0.383000	0.769657
-----	-----	-----	-----
19.730003		0.390696	2.009548
PLUG 'C'	0.454000	0.248000	1.356163
-----	-----	-----	-----
20.150001		0.261561	5.468401
PLUG 'C'	0.394000	0.384000	1.087337
-----	-----	-----	-----
19.970001		0.394873	2.831609
PLUG 'C'	0.329000	0.436000	5.280167
-----	-----	-----	-----
20.150001		0.488001	12.110475
PLUG 'C'	0.262000	0.531000	1.347244
-----	-----	-----	-----
20.060001		0.517527	2.537182
PLUG 'C'	0.196000	0.478000	0.509590
-----	-----	-----	-----
20.000003		0.472904	1.066087
PLUG 'C'	0.132000	0.357000	0.500071
-----	-----	-----	-----
20.060001		0.351999	1.400759

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.739

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.111



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
-----	-----	-----	-----
PLUG 'C'	0.133000	0.465000	7.796574
-----	-----	-----	-----
16.910003		0.388034	16.730846
PLUG 'C'	0.265000	0.739000	22.361507
-----	-----	-----	-----
16.910003		0.515385	30.259143
PLUG 'C'	0.404000	0.369000	3.257489
-----	-----	-----	-----
17.000003		0.336425	8.827886
PLUG 'C'	0.438000	0.338000	8.656908
-----	-----	-----	-----
17.000003		0.251430	25.612152
PLUG 'C'	0.405000	0.382000	4.551387
-----	-----	-----	-----
17.130001		0.336486	11.914627
PLUG 'C'	0.200000	0.654000	16.088707
-----	-----	-----	-----
16.880001		0.493112	24.600467
PLUG 'C'	0.271000	0.642000	12.855411
-----	-----	-----	-----
16.840000		0.513445	20.024005
PLUG 'C'	0.198000	0.470000	2.003950
-----	-----	-----	-----
17.210002		0.490039	4.263723
PLUG 'C'	0.131000	0.357000	2.166325
-----	-----	-----	-----
17.370002		0.378663	6.068137
PLUG 'C'	0.266000	0.485000	3.102642
-----	-----	-----	-----
17.160003		0.516026	6.397201
PLUG 'C'	0.331000	0.450000	1.830017
-----	-----	-----	-----
17.170002		0.468300	4.066706

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'C'	0.398000	0.334000	1.982045
17.230003	-----	0.353820	5.934268
PLUG 'C'	0.453000	0.211000	0.234463
17.170002	-----	0.213344	1.111202
PLUG 'C'	0.399000	0.352000	0.086802
17.200000	-----	0.351132	0.246597
PLUG 'C'	0.332000	0.446000	2.095282
17.160003	-----	0.466952	4.697942
PLUG 'C'	0.265000	0.477000	3.951013
17.260002	-----	0.516510	8.283046
PLUG 'C'	0.197000	0.477000	1.117140
17.410003	-----	0.488171	2.342012
PLUG 'C'	0.134000	0.351000	3.588658
17.240001	-----	0.386886	10.224100

THE NUMBER OF DATA POINTS IS 18

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 5.429

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 10.644

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'C'	0.133000	0.361000	4.082983
15.000001	-----	0.401829	11.310205
PLUG 'C'	0.204000	0.426000	6.755239
14.790000	-----	0.493552	15.857368
PLUG 'C'	0.272000	0.470000	2.655023
15.000001	-----	0.496550	5.648985
PLUG 'C'	0.341000	0.400000	1.743388
14.900001	-----	0.417433	4.358470
PLUG 'C'	0.403000	0.246000	4.133994
14.900001	-----	0.287339	16.804851
PLUG 'C'	0.428000	0.185000	3.524923
14.900001	-----	0.220249	19.053646
PLUG 'C'	0.404000	0.264000	2.144837
14.920000	-----	0.285448	8.124385
PLUG 'C'	0.341000	0.408000	0.990551
14.920000	-----	0.417905	2.427823
PLUG 'C'	0.271000	0.478000	1.992607
15.060001	-----	0.497926	4.168634
PLUG 'C'	0.201000	0.440000	5.307341
15.050001	-----	0.493073	12.062139
PLUG 'C'	0.135000	0.372000	3.441351
14.780000	-----	0.406413	9.250946

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.342

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.915

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'C'	0.137000	0.467000	7.735431
----- 11.960001	-----	----- 0.387645	----- 16.564094
PLUG 'C'	0.366000	0.235000	0.893777
----- 11.800001	-----	----- 0.243937	----- 3.803309
PLUG 'C'	0.344000	0.387000	9.034675
----- 11.830001	-----	----- 0.296653	----- 23.345413
PLUG 'C'	0.284000	0.393000	0.597596
----- 11.840000	-----	----- 0.398975	----- 1.520601
PLUG 'C'	0.141000	0.478000	8.390171
----- 11.890001	-----	----- 0.394098	----- 17.552658
PLUG 'C'	0.135000	0.349000	3.574800
----- 11.860000	-----	----- 0.384748	----- 10.242982
PLUG 'C'	0.208000	0.448000	0.641673
----- 11.810001	-----	----- 0.441583	----- 1.432307
PLUG 'C'	0.281000	0.376000	2.699619
----- 11.850000	-----	----- 0.402996	----- 7.179839
PLUG 'C'	0.346000	0.298000	0.515157
----- 11.840000	-----	----- 0.292848	----- 1.728714
PLUG 'C'	0.384000	0.204000	0.577893
----- 11.820001	-----	----- 0.198221	----- 2.832813
PLUG 'C'	0.350000	0.282000	0.089669
----- 11.820001	-----	----- 0.282896	----- 0.317976

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
PLUG 'C'	0.280000	0.369000	3.386760
11.620001	-----	0.402867	9.178213
PLUG 'C'	0.208000	0.433000	0.858324
11.810001	-----	0.441583	1.982274
PLUG 'C'	0.141000	0.332000	6.109506
11.840000	-----	0.393095	18.402130

THE NUMBER OF DATA POINTS IS 14

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.221

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.291

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
ARGON 2.511	0.107000	0.297000	1.607114
-----	-----	-----	-----
34.570007		0.313071	5.411159
ARGON 2.511	0.175000	0.443000	1.428288
-----	-----	-----	-----
34.470001		0.457282	3.224127
ARGON 2.511	0.241000	0.531000	3.009033
-----	-----	-----	-----
34.470001		0.561090	5.666730
ARGON 2.511	0.308000	0.602000	1.759469
-----	-----	-----	-----
34.360000		0.619594	2.922707
ARGON 2.511	0.376000	0.560000	5.960489
-----	-----	-----	-----
34.290001		0.619604	10.643732
ARGON 2.511	0.450000	0.537000	0.146019
-----	-----	-----	-----
34.290001		0.538460	0.271917
ARGON 2.511	0.451000	0.503000	3.372335
-----	-----	-----	-----
34.290001		0.536723	6.704445
ARGON 2.511	0.379000	0.581000	3.641820
-----	-----	-----	-----
34.470001		0.617418	6.268193
ARGON 2.511	0.320000	0.698000	7.294810
-----	-----	-----	-----
34.030006		0.625051	10.451017
ARGON 2.511	0.248000	0.542000	2.757549
-----	-----	-----	-----
34.470001		0.569575	5.087730
ARGON 2.511	0.184000	0.447000	2.665943
-----	-----	-----	-----
33.850006		0.473659	5.964078

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
ARGON 2.511	0.119000	0.323000	1.761663
----- 34.470001	-----	----- 0.340616	----- 5.454066

THE NUMBER OF DATA POINTS IS 12  
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.950  
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.672

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL,
ARGON 2.511	0.118000	0.318000	0.915259
----- 30.090000	-----	----- 0.327152	----- 2.878173
ARGON 2.511	0.187000	0.503000	3.430015
----- 27.510002	-----	----- 0.468699	----- 6.819116
ARGON 2.511	0.258000	0.484000	8.923114
----- 26.800003	-----	----- 0.573231	----- 18.436187
ARGON 2.511	0.330000	0.612000	1.305246
----- 28.470001	-----	----- 0.625052	----- 2.132755
ARGON 2.511	0.394000	0.612000	1.077425
----- 27.260002	-----	----- 0.601225	----- 1.760499
ARGON 2.511	0.462000	0.501000	0.867414
----- 28.050003	-----	----- 0.509674	----- 1.731366
ARGON 2.511	0.461000	0.492000	1.308751
----- 26.910003	-----	----- 0.505087	----- 2.660063
ARGON 2.511	0.396000	0.644000	3.907847
----- 28.610000	-----	----- 0.604921	----- 6.068087
ARGON 2.511	0.329000	0.635000	1.363229
----- 27.310001	-----	----- 0.621367	----- 2.146818
ARGON 2.511	0.250000	0.529000	3.810275
----- 28.080001	-----	----- 0.567102	----- 7.202789
ARGON 2.511	0.189000	0.483000	1.022172
----- 27.690002	-----	----- 0.472778	----- 2.116298



## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
ARGON 2.511	0.120000	0.329000	0.327789
-----	-----	-----	-----
27.690002		0.325722	0.996321

THE NUMBER OF DATA POINTS IS 12

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.354

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.579

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL,
ARGON 2.511	0.120000	0.328000	0.710207
24.570003	-----	0.320897	2.165266
ARGON 2.511	0.189000	0.511000	4.398156
24.570003	-----	0.467018	8.606960
ARGON 2.511	0.262000	0.515000	5.680085
24.620002	-----	0.571800	11.029291
ARGON 2.511	0.330000	0.549000	6.216026
24.570003	-----	0.611160	11.322452
ARGON 2.511	0.396000	0.561000	2.353096
24.450000	-----	0.584531	4.194467
ARGON 2.511	0.466000	0.443000	3.680545
24.880001	-----	0.479805	8.308729
ARGON 2.511	0.495000	0.389000	1.642686
24.570003	-----	0.405426	4.222844
ARGON 2.511	0.467000	0.521000	4.596043
24.570003	-----	0.475039	8.821580
ARGON 2.511	0.397000	0.608000	2.367985
24.570003	-----	0.584320	3.894713
ARGON 2.511	0.327000	0.615000	0.424456
24.570003	-----	0.610755	0.690173
ARGON 2.511	0.261000	0.603000	3.265953
24.450000	-----	0.570340	5.416175

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL,
ARGON 2.511 ----- 24.370002	0.191000 -----	0.410000 ----- 0.470361	6.036174 ----- 14.722377
ARGON 2.511 ----- 24.450000	0.121000 -----	0.260000 ----- 0.323217	6.321710 ----- 24.314270

THE NUMBER OF DATA POINTS IS 13  
 THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.668  
 THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.285

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.116000	0.312000	0.244516
21.120002		0.314445	0.783705
ARGON 2.511	0.182000	0.460000	0.670397
21.180000		0.453296	1.457385
ARGON 2.511	0.254000	0.579000	2.256894
20.870002		0.556431	3.897917
ARGON 2.511	0.324000	0.570000	2.749586
21.320003		0.597495	4.823836
ARGON 2.511	0.388000	0.554000	1.848554
21.360000		0.572485	3.336741
ARGON 2.511	0.464000	0.468000	1.812249
21.130001		0.449877	3.872328
ARGON 2.511	0.487000	0.351000	4.318983
21.360000		0.394189	12.304794
ARGON 2.511	0.460000	0.477000	1.584267
21.360000		0.461157	3.321316
ARGON 2.511	0.390000	0.550000	2.063429
21.360000		0.570634	3.751690
ARGON 2.511	0.326000	0.623000	2.500188
21.410003		0.597998	4.013144
ARGON 2.511	0.256000	0.605000	4.590523
21.430000		0.559094	7.587642

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
----- PRESSURE RATIO	-----	----- SMOOTHED DATA POINT	----- SCATTER PER CENT VAL.
ARGON 2.511	0.186000	0.458000	0.228595
----- 21.410003	-----	----- 0.460285	----- 0.499117
ARGON 2.511	0.118000	0.338000	1.958525
----- 21.430000	-----	----- 0.318414	----- 5.794453

THE NUMBER OF DATA POINTS IS 13  
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.063  
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.264

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.123000	0.337000	1.418161
17.120002		0.351181	4.208194
ARGON 2.511	0.192000	0.467000	1.524383
17.120002		0.482243	3.264203
ARGON 2.511	0.264000	0.527000	3.934562
17.150001		0.566345	7.465963
ARGON 2.511	0.331000	0.569000	1.623404
17.200000		0.585234	2.853083
ARGON 2.511	0.404000	0.461000	6.535507
16.960002		0.526355	14.176805
ARGON 2.511	0.476000	0.405000	2.874029
17.000003		0.376259	7.096367
ARGON 2.511	0.504000	0.295000	0.862121
16.710002		0.286378	2.922446
ARGON 2.511	0.478000	0.339000	2.892905
16.750003		0.367929	8.533645
ARGON 2.511	0.400000	0.562000	3.152978
16.710002		0.530470	5.610282
ARGON 2.511	0.330000	0.647000	6.208992
16.890003		0.584910	9.596588
ARGON 2.511	0.262000	0.551000	1.413095
17.000003		0.565131	2.564600

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION ----- PRESSURE RATIO	VELOCITY RATIO -----	EMPIRICAL DATA POINT ----- SMOOTHED DATA POINT	SCATTER PER CENT EFF. ----- SCATTER PER CENT VAL.
ARGON 2.511	0.194000	0.510000	2.256346
----- 16.730003	-----	----- 0.487436	----- 4.424207
ARGON 2.511	0.121000	0.343000	0.565761
----- 16.890003	-----	----- 0.348657	----- 1.649450

THE NUMBER OF DATA POINTS IS 13

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.712

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.720

## O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
-----	-----	-----	-----
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
-----	-----	-----	-----
FREON 2.511	0.128000	0.357000	1.383626
-----	-----	-----	-----
13.100000		0.370836	3.875704
FREON 2.511	0.193000	0.492000	0.930023
-----	-----	-----	-----
13.000001		0.501300	1.890291
FREON 2.511	0.304000	0.579000	0.662744
-----	-----	-----	-----
12.890001		0.585627	1.144635
FREON 2.511	0.344000	0.561000	1.005268
-----	-----	-----	-----
12.890001		0.571052	1.791921
FREON 2.511	0.408500	0.480000	1.497721
-----	-----	-----	-----
12.950000		0.494977	3.120254
FREON 2.511	0.485000	0.298000	1.939237
-----	-----	-----	-----
13.000001		0.317392	6.507508
FREON 2.511	0.478000	0.359000	2.131051
-----	-----	-----	-----
13.050001		0.337689	5.936075
FREON 2.511	0.405000	0.518000	1.719379
-----	-----	-----	-----
13.200000		0.500806	3.319266
FREON 2.511	0.312000	0.596000	1.133156
-----	-----	-----	-----
13.200000		0.584668	1.901268
FREON 2.511	0.192000	0.512000	1.226508
-----	-----	-----	-----
13.500001		0.499734	2.395524
FREON 2.511	0.126000	0.378000	1.208842
-----	-----	-----	-----
13.620000		0.365911	3.197994

THE NUMBER OF DATA POINTS IS 11

THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.348

THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.189



**SUNDSTRAND AVIATION**

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**APPENDIX C**

**TURBINE TEST SCHEMATIC DIAGRAM**

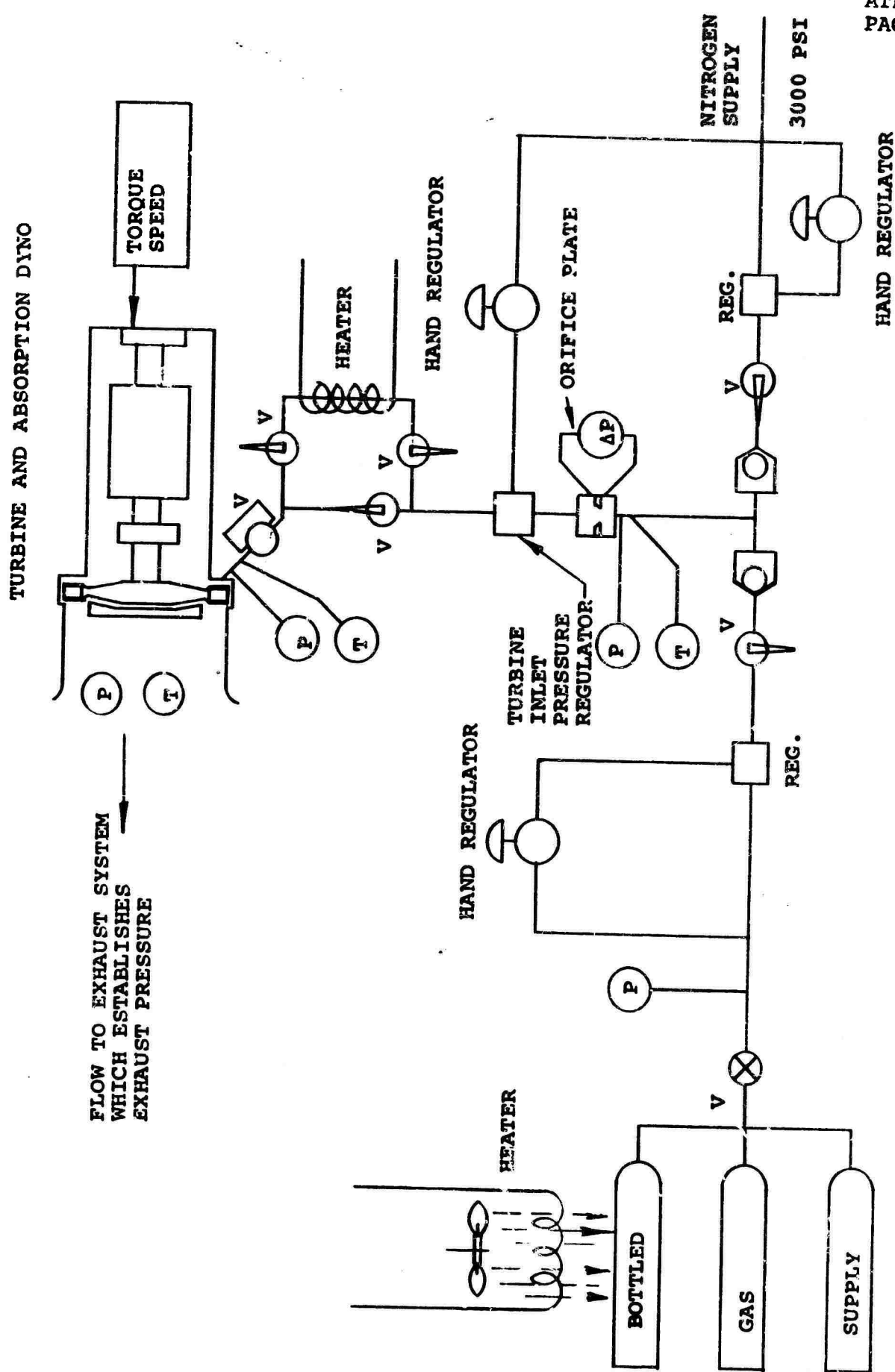


Figure 46. TURBINE TEST SCHEMATIC DIAGRAM

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**APPENDIX D**

**SAMPLE DATA SHEET**

## Sample Data Sheet

FREON 13														NOZZLE 2.511		BAR: 294	
Run 1 28 MAY '71														ORIFICE PLATE .296			
DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI		
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480		
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434		
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379		
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365		
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365		
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394		
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401		
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452		
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415		
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553		
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581		

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K	13500	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	42.85	16K	16140	0.	76.2	48.	68.	38.	7.0	250.	90.	264.4	38.2	1.365
738	12.8	21.24	19K	19200	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	19K	18810	27.	77.0	34.	85.	41.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K	15730	13.	78.0	51.	94.	42.	7.0	258.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K	12390	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.415
742	12.8	71.23	7K	7680	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K	5070	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT. #	P.R. HOM.	TQ CORR.	NS TR. RPM	NS RPM	TTE OF	DTI PSIG	TQ PSID.	TVI OF	TTI OF	PTE PSIA	PVI PSIG	PTI PSIA	PVI PSIA	APVP IN/H <sub>2</sub> O	DPV. PSI
733	12.8	102.95	5K	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	

# Sundstrand Aviation

division of Sundstrand Corporation



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July 14, 1971  
L7-ONR-190

ONR  
Chief of Naval Research  
Department of the Navy  
Washington, D.C. 20360

Attention: Mr. J. R. Patton, Jr., Code 473

Subject: Contract No. 00014-68-C-0406  
"Final Technical Report on an Analytical  
and Experimental Research Program to Optimize  
Turbine Nozzle for Off Design Performance of  
Partial Admission Turbines"

Reference: Sundstrand Letter L6-ONR-184, dated 6/24/71  
Same Subject

Gentlemen:

Please find enclosed ~~two~~ <sup>1</sup> ~~(2)~~ sets of illustrations, photos, etc.  
to replace the Xerox copies as transmitted with the original  
reports per the reference letter.

Very truly yours,

SUNDSTRAND AVIATION  
Division of Sundstrand Corporation

*J. G. Buell*  
J. G. Buell  
Contract Program Manager

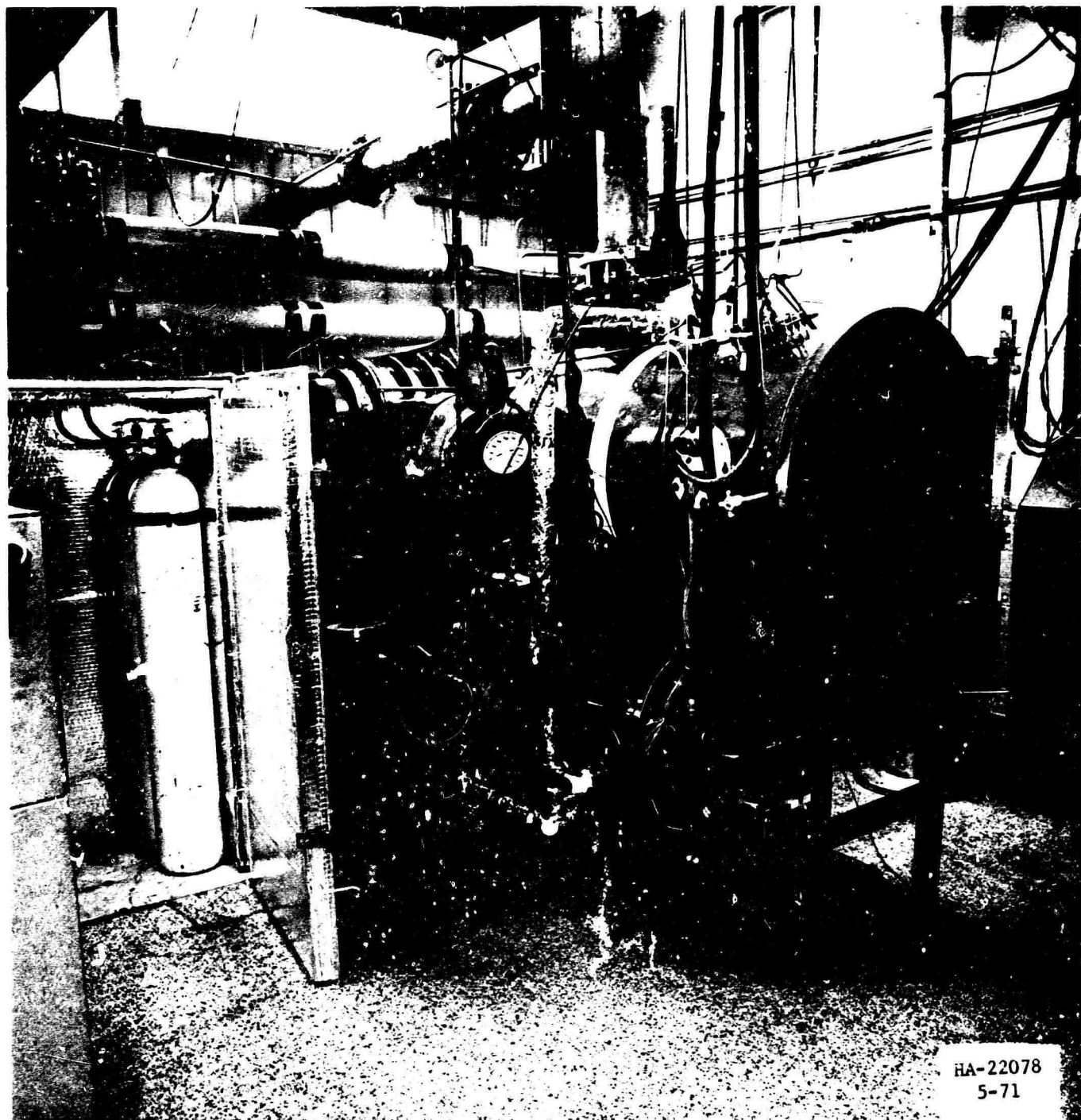
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Enclosure

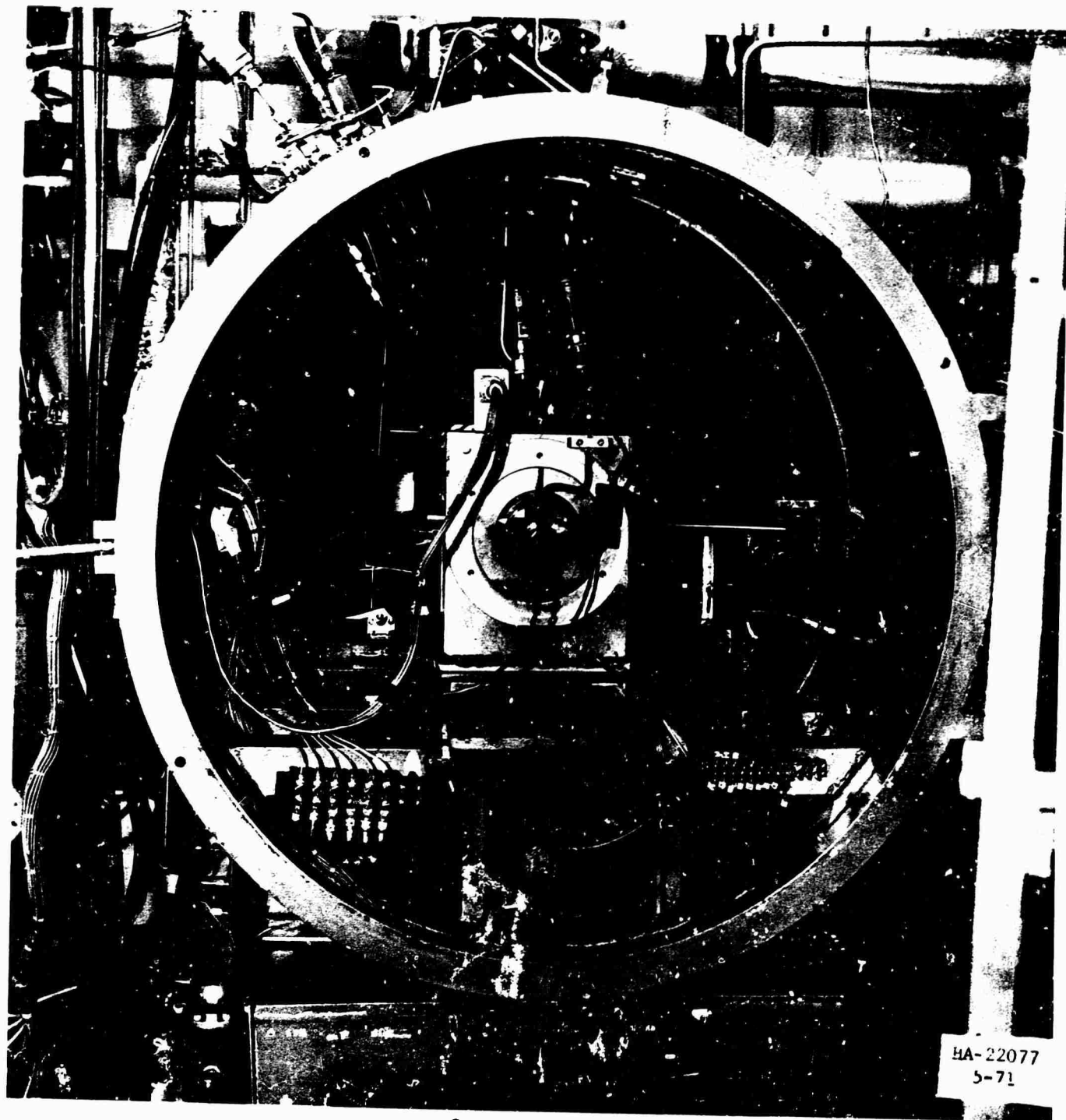
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PROPULSION, VEHICLE TRANSMISSIONS, MISSILE POWER UNITS



— FIGURE 1 TURBINE TEST  
CHAMBER AND APPARATUS. —



— FIGURE 2 INSIDE OF TEST  
CHAMBER WITH RIG INSTALLED —

HA-22124  
6-71

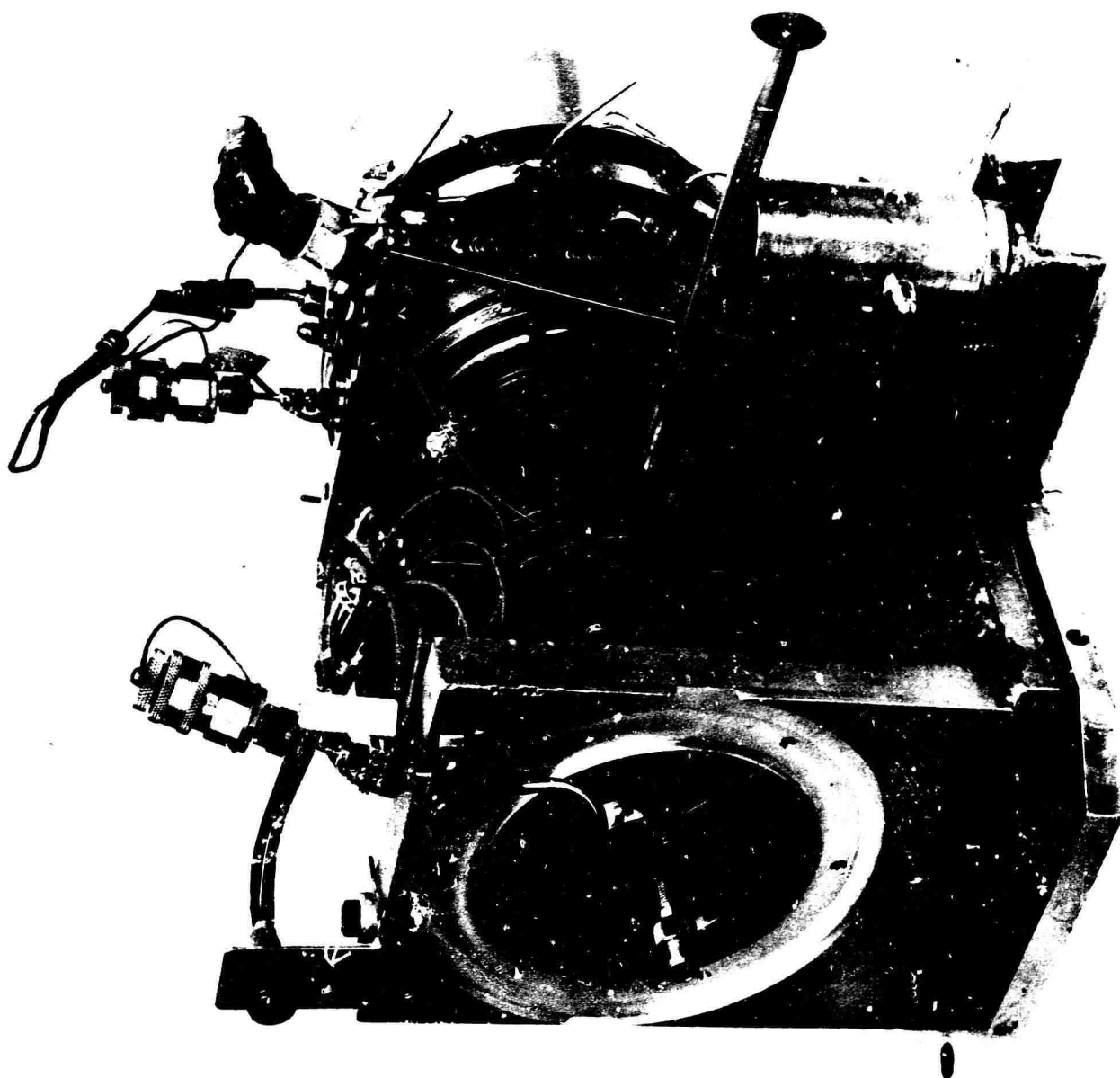
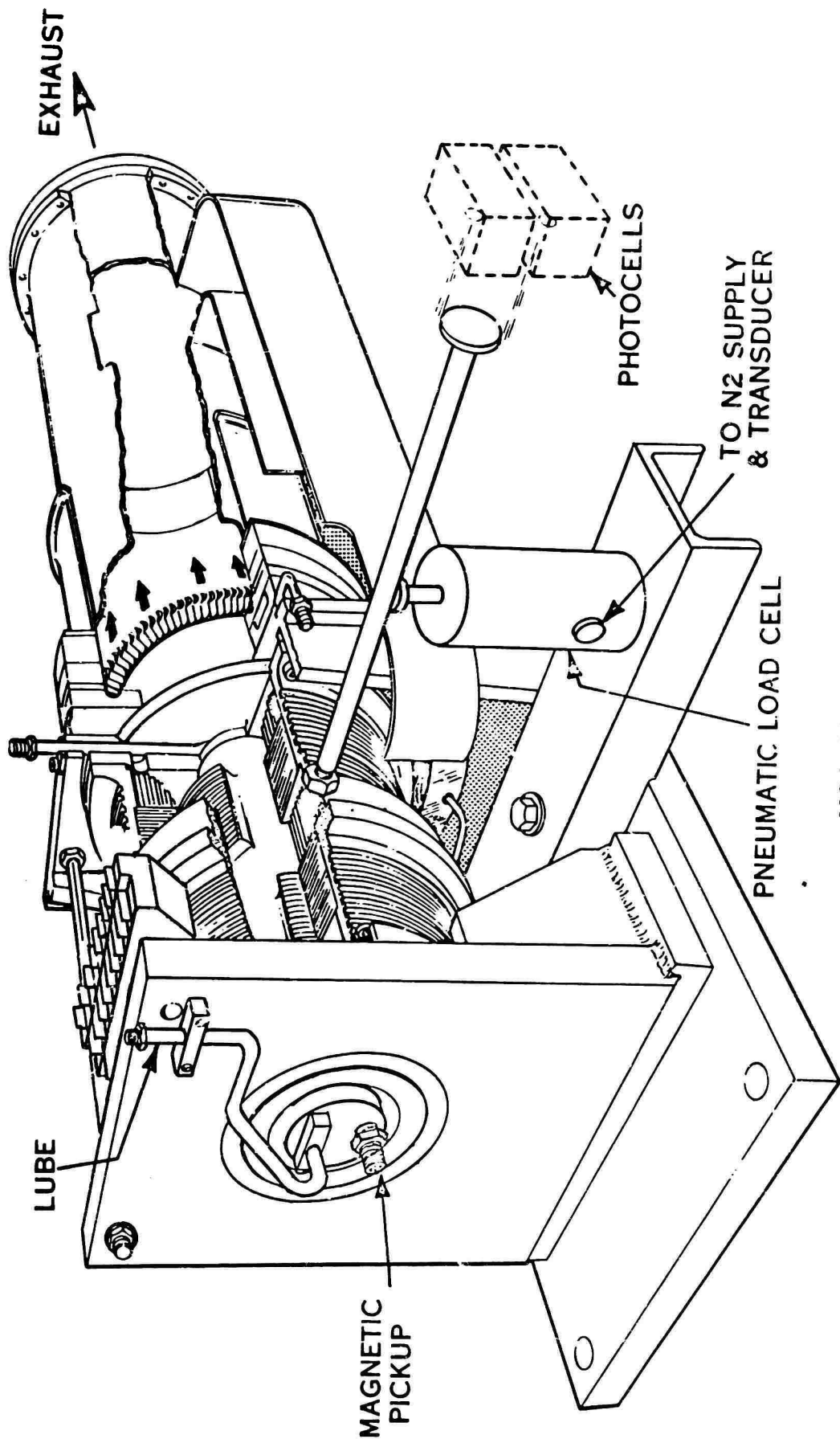


FIGURE 3 TURBINE TEST RIG





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FIGURE 4 TURBINE TEST RIG-  
DIAGRAM

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FIGURE 5 TEST RIG AND  
COMPONENTS